Testing and Performance Quantification of Acoustic Louvres

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ABSTRACT

Acoustic louvres are regularly used to control noise emissions from mechanical plant and equipment rooms, building services and industrial equipment. The sound insulation performance of acoustic louvres is quantified in a number of different ways by louvre manufacturers. While performance indicators such as insertion loss, static transmission loss, weighted sound reduction index and noise reduction are frequently used by manufacturers, do they accurately represent the in-situ sound insulation performance of acoustic louvres? In this paper a critical review of standard and non-standard test methodologies is presented. An overview of each test methodology is presented with a discussion of the advantages and disadvantages of each method. A comparison is also made of the test method results to determine whether any of them can accurately quantify the sound insulation performance of acoustic louvres.

1 INTRODUCTION

Acoustic louvres have become an accepted way to mitigate noise from mechanical plant rooms, building services and industrial equipment. However, even though they are widely used, there is a lack of consensus regarding how the acoustic performance of acoustic louvres should be tested and quantified. For example, in a survey conducted of British louvre manufacturers in 1992, Lyons (1993) found that the published performance data format varied between manufacturers and included insertion loss (IL), transmission loss (TL), sound reduction indices (SRI), noise reduction (NR) and in several instances, the manufacturer was unable to state what the published octave performance data represented.

A perusal of current acoustic louvre manufacturer websites shows that in addition to IL, TL, SRI and NR, other parameters such as field transmission loss (FTL) have been adjusted to obtain the NR (Robertson Ventilation International, 2018; NAP Silentflo, 2009), while use of single value parameters such as sound transmission class (STC) and the weighted sound reduction index (R_w) are also used to quantify acoustic performance (Price Noise Control, 2018; Louvreclad, 2018).

The use of a variety of different parameters can be confusing to acoustic consultants when trying to determine whether a louvre has a suitable acoustic performance or not. In addition, the performance data does not indicate the directionality characteristics of the louvre, with the result that the louvre under-performs in its chosen application. With these factors in mind, it is clear that a consistent method is required for the acoustic testing and performance quantification of acoustic louvres.

2 ACOUSTIC LOUVRE APPLICATIONS

To gain an understanding of the information that might be needed by a consultant when specifying an acoustic louvre the situations in which an acoustic louvre might be used need to be determined. Basically, an acoustic louvre is used as a replacement for an ordinary louvre any time free passage of air is required along with a low to moderate amount of noise attenuation. A shown in Figure 1, acoustic louvres can be used in several ways, including:

- In the walls of plantrooms and buildings to provide ventilation;
- As acoustic barriers around the edges of an external plant deck;
- To reduce noise emissions from mobile plant, equipment and machinery; and
- To allow ventilation of acoustic enclosures.

Acoustic louvres are not generally used in situations where a large volume of airflow is required (e.g. ventilation or exhaust ducts) due to the large pressure losses incurred. In those situations, acoustic attenuators are usually the optimal solution.

Figure 1: Typical uses of acoustic louvres. Clockwise from top left: Plantroom ventilation, plant deck barriers, mobile equipment and acoustic enclosures.

3 DESIGN FEATURES

The main design features of acoustic louvres are shown in Figure 2. Acoustic louvres consist of blades that have a plain upper face and a perforated under face. The blades are filled with an acoustically absorptive material, which, when the blades are angled, provides sound attenuation. The amount of sound attenuation provided by the louvre depends upon several factors, including:

- The angle of the blades;
- The mass of the blades;
- The width of the blades;
- The depth of the blades;
- The flow resistivity, mass and thickness of the acoustic absorption in-fill;
- The size and spacing of the perforations in the under face;
- The spacing between adjacent blades; and
- The number of stages.

The blades can be manufactured from a variety of materials including galvanised or powder-coated mild steel, stainless steel and aluminium. The insulation in-fill typically consists of a fire and weather resistant material such as mineral fibre batts that are cut to fit the blade shape. To reduce pressure losses aerodynamic profiles can be used for the blades at the expense of acoustic performance. The blades can be oriented horizontally or vertically and can be made to be openable and closable. A bird/rodent mesh is usually fixed to the inside face of the louvre. This mesh has no appreciable influence on the acoustic performance. The width of acoustic louvres normally ranges from 100 mm (single stage) to 600 mm (multi-stage). Louvres are not generally wider than 600mm as acoustic attenuators provide better overall performance when above 600mm long.

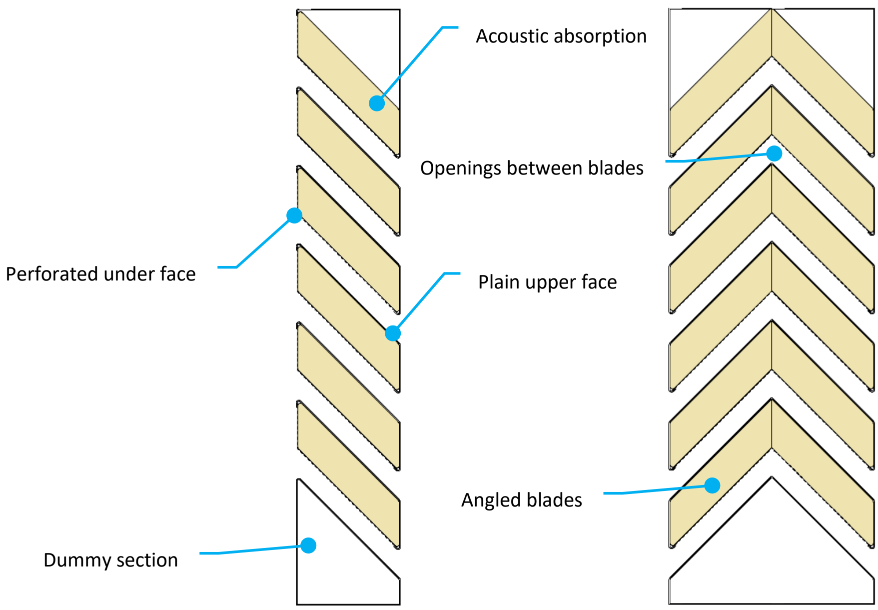
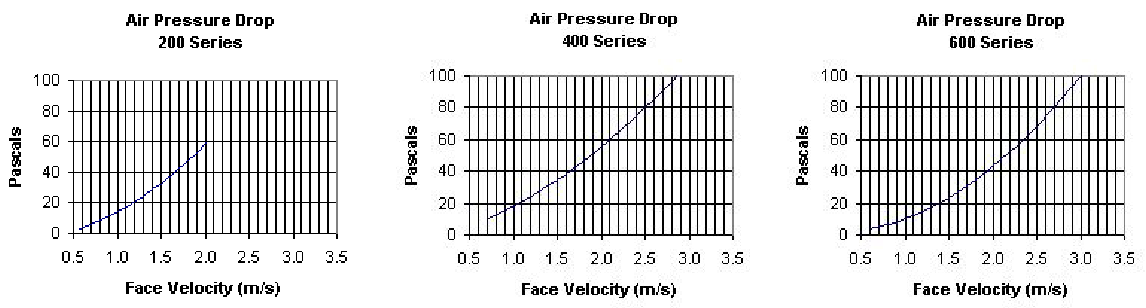


Figure 2: Design features of a typical acoustic louvre for a single stage (left) and two-stage (right) louvre

4 CHARACTERISTICS OF ACOUSTIC LOUVRES

To determine what is needed to design an acoustic louvre the characteristics that influence the overall acoustic performance need to be considered:

- Acoustic beaming is a potential issue when using single-stage louvres. Acoustic beaming occurs when there is line-of-sight through the louvre between the receiver and source(s). This usually occurs when a noise source has been installed too close to the acoustic louvre.
- Air pressure drop depends upon the face velocity (i.e. airflow) and the blade spacing. The air pressure drop can be quite significant as shown in Figure 3. While theoretically using a closer blade spacing will result in a higher level of sound attenuation, the air pressure drop will rapidly increase to a level that is too high for the fans located on the plant items being attenuated.



(Source: Acran, 2018)
Figure 3: Air pressure drop for several different louvres. The 200 Series louvres are single-stage louvres, while the 400 and 600 Series are chevron shaped two-stage louvres.

- Generated noise can occur when the airflow through the louvre is too high. Even though generated noise is a possibility, the pressure drop rapidly increases as the face velocity increases, with the result that face velocities higher than 3 m/s are rarely encountered in a properly designed system.
- Directionality is exhibited by all acoustic louvres. Research conducted by Viveiros (1998) found that at low frequencies the sound attenuation performance is nearly independent of the angle, with directionality effects increasing across the mid- and high-frequencies.

From the above characteristics keeping the face velocity low results in a lower air pressure drop and an insignificant level of generated noise. Acoustic beaming and directionality need to be considered, especially in the instance where the receiver is situated in line with or close to the blade angle of the louvre. In some applications such as rooftop plant rooms and decks, it is possible to mount the louvres upside down to prevent beaming and directionality, as long as the louvres can still prevent water ingress and achieve adequate drainage (to minimise corrosion).

5 QUANTIFYING ACOUSTIC PERFORMANCE

To quantify the acoustic performance of acoustic louvres it is necessary for the octave band performances to be stated to provide useful information to consultants and engineers. Overall values such as STC and R_w do not provide an adequate representation of acoustic performance when it is required to attenuate sound energy grouped across one or two octave bands. The acoustic performance of acoustic louvres is limited at low frequencies by mass and at high frequencies by the gaps between the louvres. Hence the performance of acoustic louvres should be specified, as a minimum, across the 125 Hz to 8 kHz octave bands, inclusive.

The octave band performance of acoustic louvres can be specified in terms of three different parameters:

1. The transmission loss or sound reduction indices;
2. The static insertion loss; or
3. The noise reduction.

5.1 Transmission Loss or Sound Reduction Indices

The transmission loss (TL) is defined as (Bies and Hansen, 2009),

$$\mathrm{TL} = 10\log_{10}\left(\frac{1}{\tau}\right) = 10\log_{10}\left(\frac{W_S}{W_R}\right) \tag{1}$$

where τ is the sound transmission coefficient, W_R is the sound power transmitted by the test element and W_S is the sound power incident on the test element.

Taking the mean free path into account and ignoring the interference patterns at the room boundaries, the diffuse field intensity can be used to determine the power that is incident upon the test element in the source room (Long, 2014):

$$W_S = I_S S_w = \frac{\langle p_S^2\rangle_{t,s}}{4\rho_0 c_0} S_w \tag{2}$$

where S_w is the area of the test element, $\langle p^2\rangle_{t,s}$ is the temporal and spatial average mean-square sound pressure in the diffuse field, ρ_0 is the density of air and c_0 is the speed of sound.

A fraction τ of the incident energy is transmitted into the receiving room $W_R = W_S\tau$ where it generates a sound pressure due to both direct and reverberant field contributions. Since the test element is a planar surface, the direct field is represented by:

$$\frac{\langle p^2\rangle_t}{\rho_0 c_0} = \frac{W_R Q}{4\pi\left[z + \sqrt{\frac{S_w Q}{4\pi}}\right]^2} \tag{3}$$

Where $\langle p^2\rangle_t$ is the temporal average mean-square direct sound pressure, Q is the directivity (dimensionless), S_w is the area of the radiating surface (m^2) and z is the measurement distance from the surface (m).

The power transmitted into the receiving room must equal the power absorbed in the receiver room. In addition, the direct field must be once reflected to enter the reverberant field. The fraction of energy incident at the walls that is reflected into the reverberant field is $(1-\bar{\alpha})$. This leads to in the receiver room:

$$\frac{\langle p^2\rangle_{t,s}}{\rho_0 c_0}=\frac{4W_R(1-\bar{\alpha})}{S_T\bar{\alpha}}=\frac{4W_R}{R_c} \tag{4}$$

Where $\bar{\alpha}$ is the total mean absorption coefficient (Sabine absorption coefficient + air loss) and includes the absorption $(S_w\tau)$ provided by the test element, $R_c=\frac{(S_T\bar{\alpha})}{(1-\bar{\alpha})}$ is the room constant due to surface reflections only and S_T is the total area of the absorbing surfaces.

The receiver room sound energy is hence:

$$\frac{p_R^2}{\rho_0 c_0}=\frac{\langle p_S^2\rangle_{t,s}S_w\tau Q}{16\pi\rho_0 c_0\left[z+\sqrt{\frac{S_wQ}{4\pi}}\right]^2}+\frac{\langle p_S^2\rangle_{t,s}S_w\tau}{R_c\rho_0 c_0} \tag{5}$$

Eqn (5) can be converted into a level relationship by taking 10 log of each side and utilising Eqn (1) to obtain the expression for the transmission between two rooms for a diffuse source field and a combination of direct and diffuse receiving room fields:

$$L_R=\overline{L_S}-TL+10\log_{10}\left[\frac{S_wQ}{16\pi\left[z+\sqrt{\frac{S_wQ}{4\pi}}\right]^2}+\frac{S_w}{R_c}\right] \tag{6}$$

where L_R is the sound pressure level at a point in the receiver room in dB and $\overline{L_s}$ is the temporal and spatial average sound pressure level in the source room in dB.

If the receiver room is very reverberant, the S_w/R_c term is much larger than the direct field term and Eqn (6) can be simplified to:

$$L_R\cong\overline{L_S}-TL+10\log_{10}\left[\frac{S_w}{R_c}\right] \tag{7}$$

Eqn (7) is used for the transmission loss between two reverberant rooms and is accurate for reverberant spaces with good diffusion. Eqn (7) is not accurate when the receiver is close to a transmitting surface or when the absorption in the receiving space is large. Care needs to be taken when interpreting the results for TL obtained using Eqn (7) when TL is less than 15 dB, due to the absorption in the receiving room being influenced by coupling with the source room (Lyons, 1994). Errors of up to 5 dB can be expected when R < 15dB (Lyons, 1994).

For sound that is radiated from an enclosed reverberant space into the outdoors there is no longer a reverberant field in the receiving space, so the room constant goes to infinity. Eqn (6) then reduces to

$$L_R=\overline{L_S}-TL+10\log_{10}\left[\frac{S_wQ}{16\pi\left[z+\sqrt{\frac{S_wQ}{4\pi}}\right]^2}\right] \tag{8}$$

If Eqn (8) is used to calculate the expected level for a receiver in the free-field close to a radiating surface where z is close to zero, Eqn (8) becomes

$$L_R\cong\overline{L_S}-TL-6 \tag{9}$$

When the distance between the transmitting surface and the receiver is large, Eqn (8) becomes

$$L_R \cong \overline{L_S} - TL + 10\log_{10}\left[\frac{S_w Q}{16\pi z^2}\right] \quad (10)$$

5.2 Static Insertion Loss

Static insertion loss (IL_{static}) is defined as the arithmetic change in sound levels with and without the acoustic louvre in place, given by

$$IL_{static} = L_{(no\ louvre)} - L_{(louvre)} \quad (11)$$

where $L_{(no\ louvre)}$ is the sound pressure level measured without the louvre in place and $L_{(louvre)}$ is the sound pressure level measured with the louvre in place. With insertion loss, the effects that the louvre has on the receiving environment are included (Lyons, 1994).

5.3 Noise Reduction

The noise reduction (NR) is the arithmetic difference in sound levels between the source and receiver sound pressure levels,

$$NR = L_S - L_R \quad (12)$$

When testing from a reverberant space to a free-field receiver located close to the radiating surface Eqn (9) applies, which can be rewritten as:

$$\overline{L_S} - L_R = NR \cong TL + 6 \quad (13)$$

6 POTENTIAL TEST METHODS

The are several standard and non-standard test methods for acoustic louvres that have been used by manufacturers to quantify the acoustic performances of their products. These test methods have been identified by the sound field(s) required for each test:

1. Reverberant to reverberant;
2. Reverberant to free-field;
3. In-duct; and
4. Impulse response.

6.1 Reverberant to Reverberant

This is the most common type of test currently used to determine the sound attenuation performance of acoustic louvres. A transmission loss suite as shown in Figure 4 is required to conduct this type of testing. The transmission loss suit consists of a source room and a receiver room. The two rooms are acoustically decoupled from each other and separated by a test aperture into which test samples are installed. The size and design of the source and receive rooms is usually set by the requirement to ensure that a diffuse sound field required for reverberant measurements is established in the receive room down to 100Hz.

The test methodology is detailed in AS 1191 (2002), ISO 10140-2 (2010) and equivalent standards, with the transmission loss or sound reduction indices being determined using Eqn (7). As previously stated, the transmission loss determined using this method is higher than the field performance of the louvre. This is due to energy feedback through the aperture containing the louvre being tested, which results in strong coupling between the source and receiver rooms and makes correction for the receive room absorption problematical.

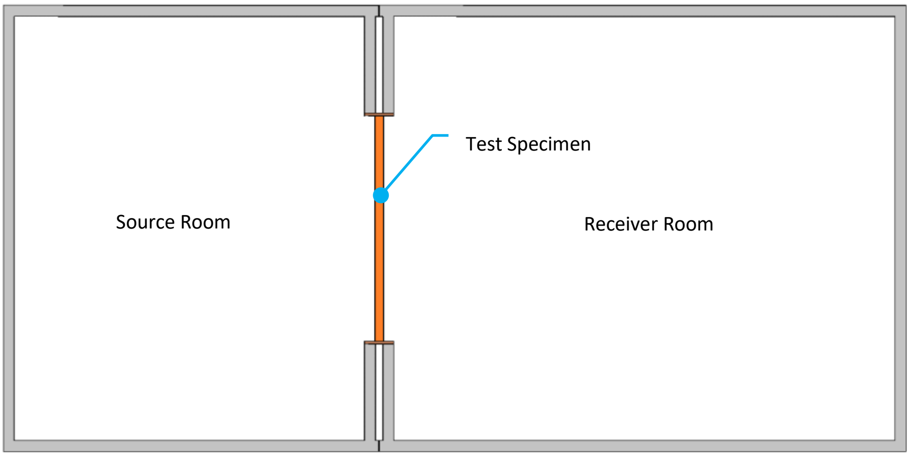


Figure 4: Transmission loss suite for reverberant to reverberant testing

London (1951) proposed a modification to Eqn (7) for low transmission loss test specimens, which is:

$$\mathrm{TL} = 10\log_{10}\left(10^{\frac{\overline{L_S}-L_R}{10}} - 1\right) + 10\log_{10}\left(\frac{S_w}{R_c}\right) \tag{14}$$

In Eqn (14), it is important to realise that R_c includes the absorption of the test specimen, but not the transmission of the test specimen. Lyons (1994) states that researchers such as Mulholland and Parbrook (1965) found improved accuracy using Eqn (14) compared to Eqn (7), with errors of up to 2.5 dB being obtained where the test specimen had a transmission loss of less than 10 dB. They also found better results were obtained when only the first few decibels of the reverberation time decay curves were used. Mariner (1961) proposed an alternative procedure involving the use of a calibrated source and substituting a non-absorbent panel with a transmission loss performance greater than 15dB for the test specimen to remove difficulties associated with measuring the receiver room sound absorption.

Bies and Pickles (1974) and Bies and Davies (1977) utilised a procedure based upon the measurement of level differences in both directions and the decay times in both the source and receiver rooms. This procedure is complicated as it requires iterative calculations using nine different equations to converge to a satisfactory solution.

6.2 Reverberant to Free-Field

Reverberant to free-field replicates the typical acoustic louvre installation in an external wall of a plantroom. A reverberant sound field is created within the source room. The sound pressure level is then measured external to the source room in free-field conditions (either external to the building or an in anechoic room).

Figure 5 shows the different test configurations that can be used for reverberant to free-field testing. For static insertion loss testing measurements are made in the far field with and without the louvre in the aperture. Eqn (11) is then used to calculate the static insertion loss. By rotating the louvre in the aperture by 90^o and making measurement in the far field at different angles, the directionality of the louvre can be measured. A similar test arrangement was proposed by the HEVAC Association Acoustics Group (1991) in a draft test guideline that was released for comment. That draft test guideline did not include rotating the louvre 90^o, which is necessary to obtain the directivity characteristics of the louvre.

If measurements are made of the average sound pressure level in the source room close to the test specimen and in the near-field external to the louvre as shown on the right-hand side of Figure 5, it is possible to measure the noise reduction of the louvre as described by Eqn (12). This measurement procedure was proposed in Section 2.3 ‘Test Procedure for Measuring Transmission Loss in Non-Laboratory Type Configuration’ of the superseded standard ASTM E336-67T (1967) to determine the field Transmission loss of building elements using Eqn (13). Measuring the noise reduction does not allow the directivity of the louvre to be quantified.

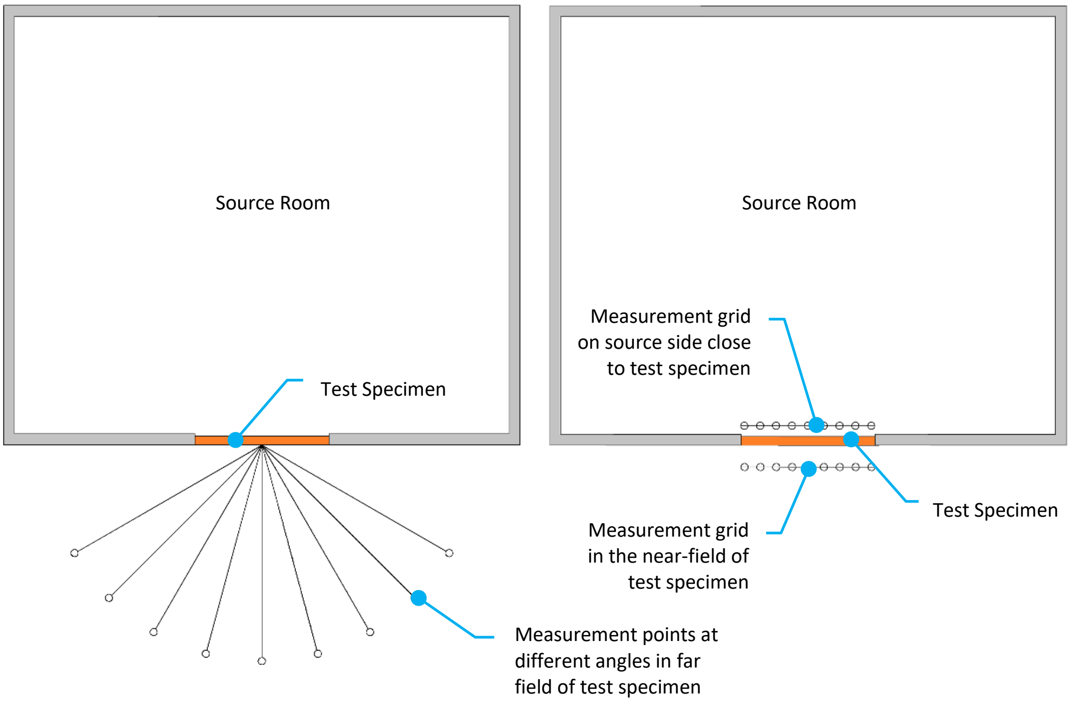


Figure 5: Test configurations for reverberant to free-field testing. The left side shows insertion loss test arrangement while the right side shows noise reduction test arrangement

6.3 In-Duct

In-duct testing is commonly used measure the performance of silencers for use in ducts and pipes. Two types of in-duct tests are usually used for duct silencers – static insertion loss (IL_{static}) and generated noise level (Sharland, 1972). The methodologies for both tests are contained in standards such as the withdrawn AS 1277 (1983), ASTM E477-13e1 (2013) and similar standards.

In the static test, the silencer is placed near the centre of a long duct, with a sound source at one end and a termination at the other end as shown in Figure 6 With the source operating, the mean sound pressure level, $L_{(louvre)}$, is measured across a section of the duct some distance downstream of the silencer. The silencer is then removed and replaced with the same length of plain duct. The average sound pressure level at the same measuring station is again determined, $L_{(no\ louvre)}$, and the insertion loss calculated using Eqn (11) if the cross-sectional area of the outlet duct with and without the louvre is the same (AS 1277, 1983).

The discharge of the duct can be to a reverberation chamber for the diffuse field method or an anechoic chamber/external environment. If a reverberation chamber is used, it is important to ensure that the axis of the outlet duct is not perpendicular to the opposite wall of the test room. For an anechoic chamber or discharge to the external environment, an anechoic termination (and coupler if required) must be fitted to the outlet duct (Sharland, 1972).

As stated earlier, measurement of the generated noise from acoustic louvres is not required at typical face velocities of ≤ 3 m/s. However, if desired, generated noise can be measured using a static insertion loss duct and reverberation room (Sharland, 1972). As shown in Sharland (1972), on the upstream side of the louvre the static sound source is replaced by a fan, which provides a “quiet” flow through the test louvre via a permanent silencer. On the downstream side of the test louvre the only noise will be that generated by the flow itself. The noise entering the reverberation room from the end of the duct can be measured and the sound power, L_w, calculated using

$$L_w = \overline{L_p} + 10\log_{10} V - 10\log_{10} T - 14 + X_r \tag{15}$$

Where $\overline{L_p}$ is the temporal and spatial average sound pressure level in the reverberation room in dB, V is the volume of the reverberation room in m^3, T is the reverberation time in seconds and X_r is the end reflection factor of the duct in dB. As for the static insertion loss, the duct could open into an anechoic chamber or to outside and the sound power level of the flow generated noise measured by a free-field traverse.

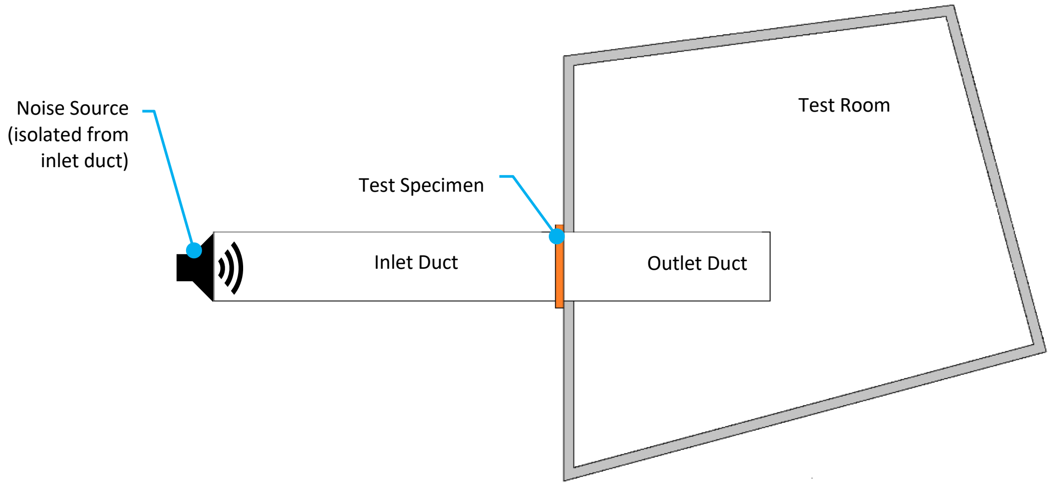


Figure 6: Schematic of the in-duct test configuration. The test room can be either a reverberation chamber for the diffuse field method or free-field (anechoic room or external to building).

6.4 Impulse Response

The principle of the impulse response method is to isolate the sound travelling through the test sample from the sound that travels around the test sample. This is done by ensuring that the test consists of a short duration (i.e. impulsive) signal that travels through the test sample and is recorded before the flanking sound arrives.

A detailed overview of the impulse response method is presented in Lyons (1994), Viveiros (1998) and Viveiros, Gibb and Gerges (2002). The sound source is a speaker that points towards the louvre and emits an impulsive noise at a constant sound pressure. The sound pressure level time history is recorded on the other side of the louvre at various positions. The measurements are done with and without the louvre in place. The results are then post-processed, and the static insertion loss determined by subtracting the portions of the signals containing the direct component from each other.

The prime advantage of the impulse response method is that it does not require the use of expensive test facilities, with the testing able to be conducted outside or within a room.

7 SUMMARY AND CONCLUSIONS

This paper has presented a brief review of the common uses of acoustic louvres, design features and performance characteristics to enable an understanding of the acoustic performance indicators required by acousticians. In addition to the acoustic attenuation, information is required regarding the directivity characteristics of the louvre.

The analysis has determined that transmission loss testing between reverberant spaces may be unsuitable for acoustic louvres due to the coupling that exists between the source and receiver rooms. While there are several methods that can be implemented to reduce the uncertainty in the transmission loss performance due to this coupling, transmission loss testing does not quantify the directionality of the louvre.

Testing an acoustic louvre using a reverberant to direct methodology closely replicates the most common use of acoustic louvres. If the static insertion loss is measured using measurement locations positioned away from the test specimen the directionality of the louvre can be quantified. Conversely, measuring in the near-field of the louvre allows the noise reduction to be measured at the expense of being able to quantify the directionality.

In-duct static insertion loss measurements utilise the same measurement method used for acoustic attenuators. However, as acoustic louvres are rarely (if ever) located in ducts the insert loss performance measured using this method may not be applicable to louvres mounted in the external wall of the plantroom. In addition, in-duct measurements do not allow the directionality to be measured.

Impulse response testing allows the static insertion loss to be measured without using expensive test facilities. However, the impulse response method does not allow random incidence testing as encountered in plantrooms.

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