SOUND PRESSURE LEVELS IN A REVERBERANT VOID

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Summary

Sound pressure levels in a reverberant area are investigated. The sound energy introduced into the area is calculated, and from that a form of room acoustics theory is utilised to predict sound pressure levels at specific points within the area. Monitoring at the same points allows a comparison to be made between measured and predicted levels.

A good fit exists between measured and predicted sound pressure levels. This indicates that the model is viable as a means of describing sound pressure levels in yards or small open areas that are analogous with rooms.

An understanding of the distribution of the sound in such spaces can lead to the specification of noise control measures. Thus the project can become a useful basis for further noise control measures if needed in this type of situation.

Introduction

The reverberant area examined is a lightwell at the rear of a City centre restaurant in York. The property is a Grade II listed building. There is a self contained flat at second floor level above the restaurant. The isometric drawing at figure 1 shows the dimensions of the light well and the location of the extract ventilation system of the restaurant.

The novel approach of using a model based on room acoustics in the context of an open area is an attempt to establish whether or not a reasonable fit exists between sound pressure levels calculated from theory and levels actually monitored. If a correlation exists, as in the case from the results obtained, then the model can be used to explain and resolve the high noise levels in this particular light well, and other similar situations.

Source of Sound Power

Before prediction of sound pressure levels in the lightwell can be undertaken the sound source must be identified and quantified. Figure 1 shows that the ventilation system to the restaurant kitchen comprises two ducts joined at a height of 3 m then forming a single cylindrical, vertical duct discharging to atmosphere at chimney level. The metal duct is constructed in 0.9 mm gauge galvanised steel and is of 0.3 m diameter. An axial fan, with bifurcated duct around it operates the system.

Preliminary work including 1/3 octave band analysis indicated that low frequency harmonics were present. Subjective assessment also indicated that resonance along the vertical section of the duct results in sound propagation in the manner of a line source. This means that whilst the fan itself is a point source, sound in the form of breakout from the duct, is radiated in a series of concentric cylindrical surfaces with axis along the duct. The duct becomes a line source.

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ISOMETRIC VIEW OF LIGHTWELL SHOWING FAN AND DUCT

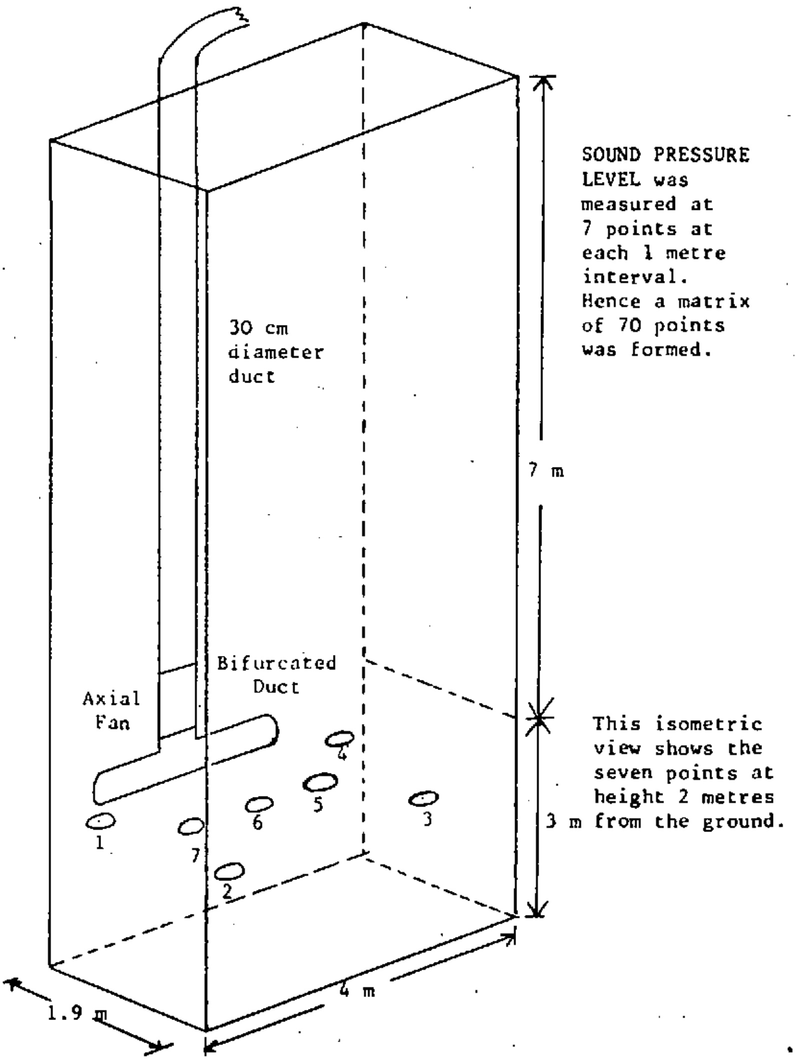

Figure 1

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Within seconds of the ventilation system being switched on steady acoustic conditions exist within the light well. There is no other significant intrusion in the noise climate.

Measurement of Sound Pressure Levels

Procedure The major difficulty was ensuring that monitoring was at exactly each of the 70 matrix points. The height of the light well and location of windows opening into it meant that a broom shaft was needed to extend reach. The condenser microphone was securely fixed to the shaft, as an extra precaution a windshield was placed over the microphone in case it banged against the walls. This being a risk owing to the unwieldy nature of the broom shaft, even when fixed to a tripod to provide stability.

Despite the relatively crude method of extending the microphone reach it was possible to accurately locate each of the 70 points. This was done by counting bricks, the most difficult points to establish were consequently the three centres at each 1 m interval. Each of the four corner points is 0.5 m from both walls. The three centre points are 1 m apart.

The CEL Impulse Integrating Sound Level Meter model 193/2 was used for monitoring. The instrument was calibrated at 1 kHz 114 dB(A) both before and after monitoring. The instrument has analogue read off and was set to slow response. A microphone cable was used.

Possible errors Source of possible instrumentation error are as follows:

(a) Analogue readoff, an error of plus or minus 3 dB(A) was possible.

(b) Microphone cable, an error of plus or minus 2 dB(A) possible.

(c) The microphone itself. In the reverberant field random incidence response should apply. However several of the 70 matrix points are within 1.5 m of the axial fan. An error of plus 5 dB(A) is possible.

Elsewhere the microphone could be responsible for an error of plus or minus 2 dB(A).

In conclusion a possible error of plus or minus 4 or 5 dB(A) can be anticipated. Close to the axial fan itself monitored levels may be 5 dB(A) higher than predicted.

Theory

The motion of sound waves within any three dimensional structure is a complicated study. The usual category of research is rooms. However the light well under investigation here is of similar dimensions, with similar surfaces to a room. The major difference is that the top of the box formed by the light well is open to the sky. Effectively though the light well is a room, one end wall of which is a perfect absorber,

The light well provides a reverberant room model: where it is impossible to measure direct and reflected sound separately. The field in the void is

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diffuse since the interior surfaces contribute together to provide multiple reflection of the sound waves. Accurate plans of the building, were available and were used to ascertain the surface areas of each material and subsequently the total absorption of sound within the light well.

Breakout from the duct provides a continuous energy supply into the light well. Breakout is calculated from the sound power level in the duct, detail of the duct, including sound reduction index.

Calculation of breakout, which is direct energy, summed, with indirect energy: that proportion of sound not absorbed but reflected within the light well, gives a total energy prediction.

This figure, corrected to dB(A) can then be compared with sound pressure levels monitored in dB(A). Consequently the effectiveness of the model can be assessed.

Some deviation of sound levels monitored will be expected because of the voids normal modes of vibration. It is known that the duct provides a steady signal with harmonics present. The light well is fairly small, but even so some excitation of the normal modes might be expected at resonant frequencies as a standing wave is established.

Because different sound pressure levels are expected a matrix of 70 different readings, at different points within the light well is compiled. Sound pressure levels are predicted at each of the 70 monitoring points.

Predicted SPL's : equations used

(i) $$SPL = SWL_B + 10 \log_{10} \left[\frac{Q}{4\pi r^2} + \frac{4}{R_c}\right]$$

SPL = sound pressure level, dB
SWL_B = sound power level [duct break out], dB
r = distance from source, m
R_c = room constant
Q = directivity factor

(ii) Directivity Factor Q = 2, duct runs along one wall of void.

(iii) Sound Power Level of Fan
$SWL_D = 130 + 20 \log KW - 10 \log Q$
SWL_D = sound power level of fan
kW = kilowatt rating of fan, KW
Q = Volume flow, m^3/h

(iv) Duct breakout
$$SWL_B = SWL_D - R + 10 \log \left(\frac{SW}{S_D}\right)$$

SWL_B = sound power level in void, dB
SWL_D = sound power level in duct, dB

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R = Reduction Factor
SW = total surface area of duct radiating into void, m^2
S_D = cross sectional area of the duct, m^2

Since $10 \log \left[\frac{SW}{S_D}\right] \geq R$ it has been assumed that half the sound power in the duct breaks out and the rest carries along the system ie $SWL_B \leq \left(SWL_D - 3\right)$ dB

Table of Comparative SPL measurements

Height/m	Predicted SPL_{AV}/dB(A)	Measured SPL_{AV}/dB(A)
1	60	62
2	60	62
3	62	65
4	62	65
5	62	65
6	62	65
7	62	63
8	62	63
9	62	62
10	62	61

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Location by 1 m Matrix Pattern

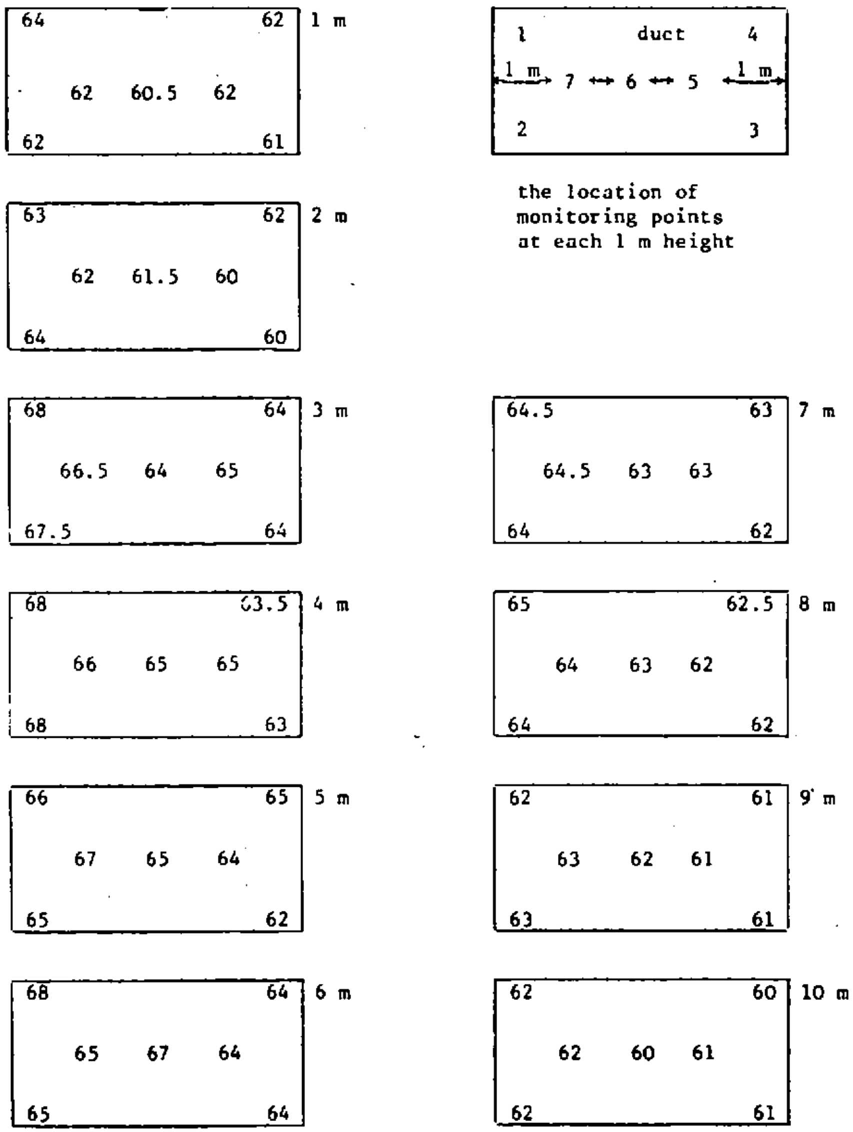

Figure 2

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Conclusions

1. There is good fit between sound pressure levels predicted using theory and levels actually monitored.

2. In only nine of the 70 points of the matrix was there a difference between predicted and measured levels that is not accountable to instrumentation error and in all nine instances the difference was only 1 dB(A).

3. The closest fit between predicted and monitored sound pressure levels is at point 7 of each 1 metre height interval. This point is the nearest to the duct and is away from the corners of the area.

4. The highest sound pressure levels monitored at each 1 metre interval are in the corner nearest to the duct. Where direct and reflected energy both make significant contributions.

5. At height intervals 3 and 4 metres up the light well the largest differences between calculated and monitored levels occur. Typically monitored levels are 3, 4 or 5 dB(A) above those predicted.

Discussion

The model works in so far as sound pressure levels monitored correlate with those predicted.

The part of the reverberant light well wherein differences between the two are greatest is at heights 3 and 4 metres from the floor. That is in the vicinity of the fan. This indicates that although the model approach, treating breakout from the duct as a line source works there is still a direct contribution to overall energy from the axial fan.

Where reflection of sound is most complex; in corners, levels monitored are proportionally higher than in the centre. This confirms what would be expected in corners, an increased contribution from reflected sound.

Sound pressure levels predicted are identical for the top seven tiers of the matrix because the duct is treated as a line source. Thus at each 1 m height the distance of each of the seven monitoring points from the source does not differ. In reality, as proven by monitoring, levels are not uniform at each height interval. This is because pressure nodes within the light well comprise a standing wave. A further reason for differences with height is that reflection of sound decreases towards the top of the light well and the open sky.