THE ATTENUATION OF NOISE ENTERING BUILDINGS USING QUARTER-WAVE RESONATORS: RESULTS FROM A FULL SCALE PROTOTYPE

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ABSTRACT
This paper continues ongoing research into the use of quarter-wave resonators for the attenuation of noise entering buildings. Previous work involving scale model experiments demonstrated the effectiveness of a multi-cavity resonator system, achieving significant attenuation in the third octave bands to which the resonators were tuned (Field and Fricke 1995a, 1995b, 1995c, 1996). Results for experiments with a full scale prototype are now presented, demonstrating the feasibility of such a device for the attenuation of noise entering buildings.

1 INTRODUCTION
Experiments were carried out on a full scale prototype quarter-wave resonator system. The aim was to use the results from model experiments to construct and test a working prototype installed at a residence exposed to road traffic noise. Experimental results are presented for various noise sources, demonstrating that the full scale quarter-wave resonator system is capable of providing significant levels of attenuation for different types of road traffic.

2 EXPERIMENTAL SET-UP
The set-up used in full scale experiments is shown in Figure 1. The room used in full scale experiments was located in an inner city suburb of Sydney. The room was used as a bedroom located on the top floor of a double storey terrace house. The dimensions of the room measured 5.2 × 4.0 × 3.0m high. Contained within the facade facing the street was a window with dimensions 1.54 × 0.84m. Half the window area was openable. There was also a pair of openable doors in the facade, permitting access to a balcony outside the bedroom. The openable section of the window was replaced with a panel insert made of chipboard with 20mm thickness containing a ventilation opening. The panel was completely sealed at the edges with an appropriate sealant ensuring that there were no air gaps between the facade and the panel.

Permanently attached to the panel was a frame which was used to position the resonator system accurately at the ventilation opening. The ventilation opening dimensions were 665mm × 90mm. The aspect ratio of the opening was therefore 7.4:1. The area of the opening represented 9.5% of the openable area of the window.

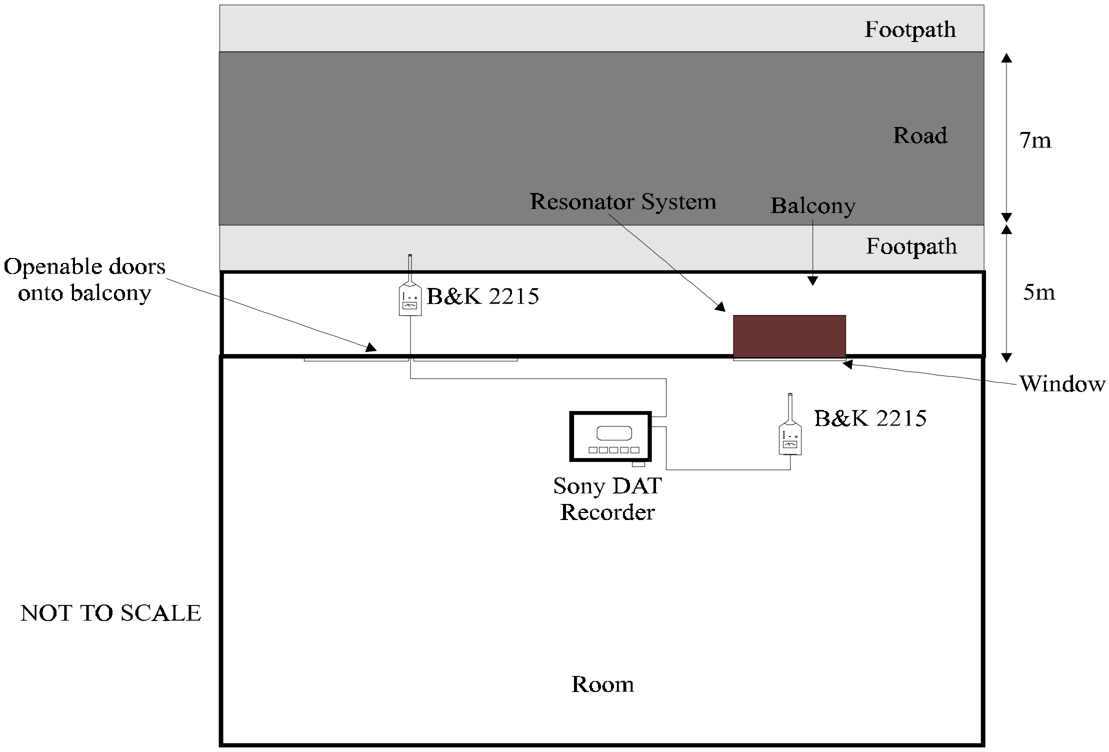

Figure 1: Set-up Used for Full Scale Experiments

2.1 NOISE SOURCES

Experiments were carried out using a number of possible traffic noise sources to assess the performance of the full scale resonator system thoroughly. Short-term noise measurements involving the passage of individual vehicles on the street adjacent to the residence were carried out. Controlled "drive-bys" of known vehicles were used as the noise sources. Drivers were instructed to drive along the street in a normal and consistent manner. Individual vehicles parked outside the residence in idling mode were also used as continuous noise sources. It was ensured that the noise emitted by the idling vehicles was significantly higher than background noise levels to avoid contributions from other neighbourhood activities. Finally, the time varying nature of traffic noise as a collection of vehicles was taken into account by carrying out long-term noise measurements with local traffic activities as the noise source. Sufficiently long time periods were used to ensure a satisfactory representation of local traffic activities was obtained. In addition to road traffic, other noise events included in the measurements involved aircraft activities, construction noise and the activities of local residents.

2.2 GENERAL EXPERIMENTAL TECHNIQUE

To determine the performance of the resonator system, the different noise sources described in section 2.1 were used in experiments to obtain a noise level difference of noise measured inside and outside the room with and without the resonator system located at the ventilation opening.

The calibrated Brüel and Kjær type 2215 Sound Level Meters were placed in their specified positions inside and outside the room. The sound level inside and outside the room was measured and recorded onto digital audio tape (DAT) as the known noise sources operated on the street adjacent to the residence. These measurements would serve as reference sound levels inside and outside the room from which the performance of the resonator system could be determined. The difference between the measured levels inside and outside the room gave an indication of the transmission loss of the facade without a quarter-wave resonator system in position at the ventilation opening. The experiment was repeated three times and the results arithmetically averaged to account for slight variations in driving technique and any extraneous noise from other neighbourhood activities. The resonator system was then placed around the ventilation opening. The sound level was then re-measured inside and outside the room and recorded onto DAT as the known noise sources operated again on the street adjacent to the room. The difference between the sound levels measured inside and outside the room gave a measure of the insertion loss provided by the facade with the quarter-wave resonator system in place.

The DAT recordings of the sound levels measured inside and outside the room with and without the resonator system in position were analysed using a Brüel and Kjær Type 2131 Spectrum Analyser in third octave bands. The frequency range of interest was 31.5Hz to 10kHz. For the "drive-bys" of individual vehicles, a linear average was taken over an eight second time period during the noise event. For measurements of idling vehicles, three eight second linear averages were taken over a one minute measurement period. Long-term measurements of traffic activities were analysed using a Larson Davis Type LD2900 Dual Spectrum Analyser over a 15 minute time period. All analysed noise levels were A-weighted.

2.2.1 CORRECTION TO MEASURED SPECTRA

The room used in full scale measurements had three significant transmission paths other than the ventilation opening itself. These paths were:

- the chipboard panel which replaced the openable area of the window
- the fixed upper half of glazing of the window
- the glazing in and air gaps around the doors used to access the balcony

These additional transmission paths were unavoidable since the resonator system was retro-fitted to an existing window in a room. It was not possible to alter the facade of the room permanently to facilitate the installation of the resonator system. If this system were to be developed commercially, the resonator system would be installed in a facade using the same materials as the rest of the facade rather than using a panel to replace the window area.

As a result of multiple sound transmission paths into the room, the noise level measured inside the room with and without the resonators in position at the ventilation opening represented the contribution to the noise level inside the room from all possible transmission paths, not only through the ventilation opening. Consequently, the true performance of the resonator system for attenuating noise entering the room through the ventilation opening only is not realised. The minimum noise level in some third octave bands is limited by noise entering the room by other transmission paths.

A correction could be made to the measured spectra inside the room with and without the resonator system located at the ventilation opening which enabled the contribution of sound transmitted through the ventilation opening to be isolated from the sound transmitted via all the other transmission paths collectively. By closing and sealing the ventilation opening in the panel, the sound level inside the room resulting from the collective contribution of all sound transmission paths not including the ventilation opening could be measured. Hence the sound level inside the room resulting from the contribution of sound propagation through the ventilation opening only could be determined by the sound pressure level difference in third octave bands between the spectrum measured inside the room with a ventilation opening and the spectrum measured inside the room with the ventilation opening closed and sealed.

2.3 RESULTS

Results are presented from a series of experiments involving the different noise sources described in section 2.1.

2.3.1 "DRIVE-BY" OF AN INDIVIDUAL VEHICLE

Various known vehicles were used as noise sources to demonstrate that the resonator system provided significant attenuation of noise for a wide range of vehicle types involving different time varying noise characteristics. The results from experiments with a medium sized passenger vehicle (Mazda 323 Astina) are presented and are representative of the results obtained for other individual vehicles.

Figure 2 shows the A-weighted noise spectra measured inside the room with and without the resonator system in position at the ventilation opening as the medium sized passenger vehicle drove by, representing the respective noise levels heard inside the room including contributions from all sound transmission paths.

After the spectra measured inside the room were corrected, 8dB(A) attenuation of noise entering the room through the ventilation opening was achieved by the resonator system. Attenuation levels in the third octave bands to which the resonators were tuned ranged from 11 to 20dB, with the resonators tuned to frequencies in the range of 1 to 2kHz performing most effectively. The reduction in level in the 250Hz third octave band by the presence of the resonator system is thought to be a result of the added mass of the resonator boxes in contact with the chipboard panel suppressing a resonance of the fixed window glazing excited by the passing vehicle.

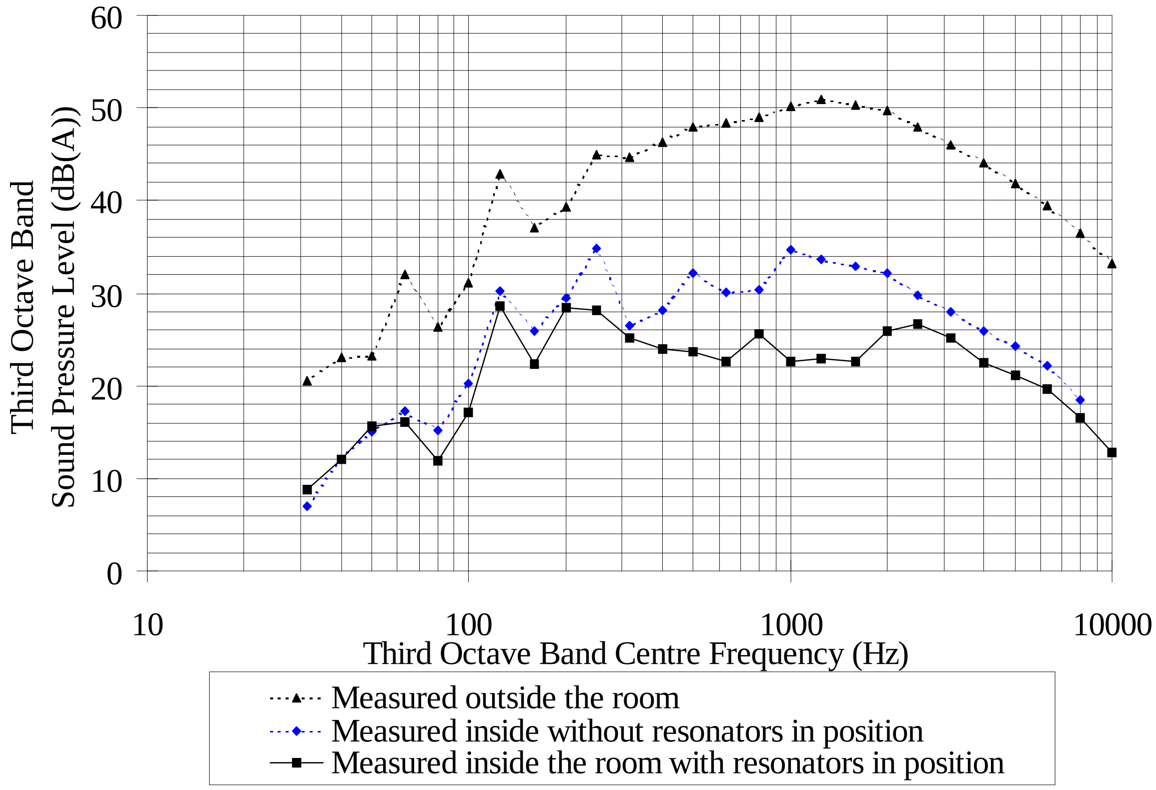

Figure 2: Noise Spectra Measured for the "Drive-by" of a Medium Passenger Vehicle

2.3.2 CONTINUOUS NOISE SOURCE - IDLING VEHICLE

In addition to evaluating the performance of the quarter-wave resonator system for time varying traffic noise, its effectiveness for reducing the level of steady, continuous noise was also investigated. Individual vehicles idling outside the room were used as continuous noise sources. To ensure that the idling vehicle was the dominant source in the noise environment, only vehicles with an idling noise level of 10dB(A) above the existing background noise level measured outside the room were used in experiments. The results from experiments with a motorcycle (Yamaha YZF750) are presented.

Figure 3 shows the A-weighted noise spectra measured inside the room with and without the resonator system in position at the ventilation opening as the motorcycle operated in idling mode, representing the respective noise levels heard inside the room including contributions from all sound transmission paths.

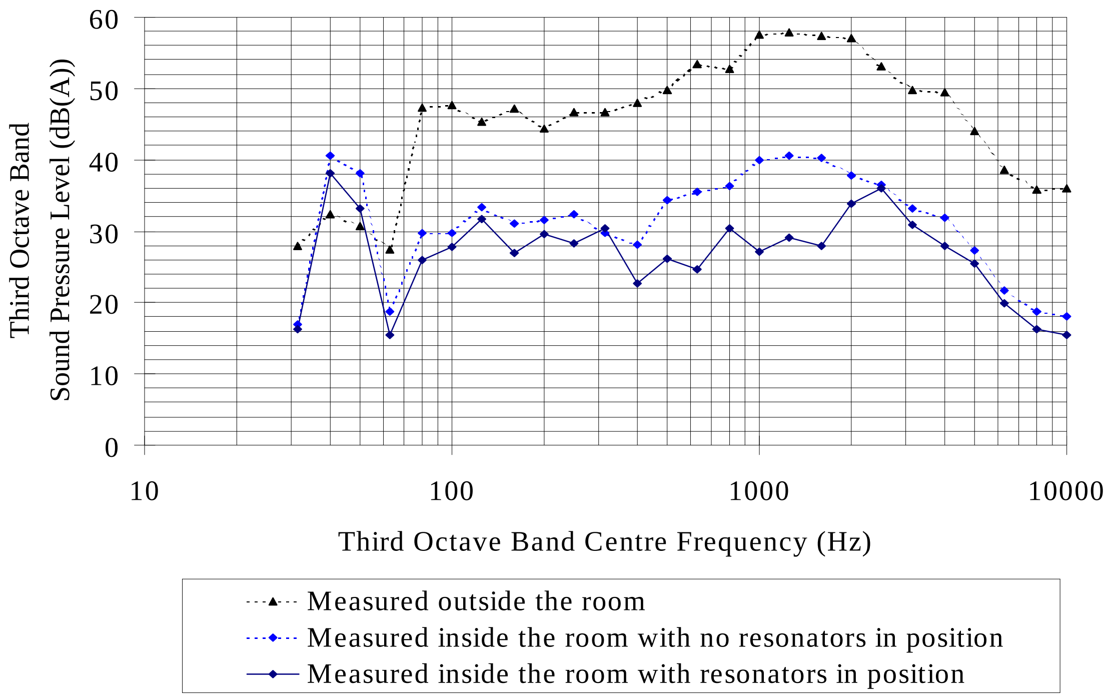

Figure 3: Noise Spectra Measured for the Idling Motorcycle

After correction of the spectra measured inside the room, the overall attenuation of noise entering the room through the ventilation opening provided by the resonator system was 8dB(A). Attenuation levels in the third octave bands to which the resonators were tuned ranged from 11dB to 22dB. From Figure 3, there is an increase in sound level measured inside the room in the 40Hz and 50Hz third octave bands. This is likely to be a panel resonance that has been excited by the noise emitted by the idling motorcycle.

2.3.3 LONG-TERM MEASUREMENTS OF LOCAL NOISE EVENTS

Experiments were carried out involving local traffic activities as the principal source of noise. Measurements were made over a 15 minute time period with and without the quarter-wave resonator system in position at the ventilation opening. In addition to vehicles passing by on the street adjacent to the residence, other noise events which contributed to the overall noise environment included aircraft flyovers, distant construction noise and the activities of local residents. The measured noise levels are presented in terms of the ($L_{Aeq,15min}$) in third octave bands.

Figure 4 shows the A-weighted equivalent noise level over the 15 minute time period measured inside the room with and without the resonator system in position at the ventilation opening, representing the respective noise levels heard inside the room including contributions from all sound transmission paths. The noise level measured outside the room has also been included. It should be noted that the overall $L_{Aeq,15min}$ measured outside the room with and without the resonators in position had a difference of 2dB(A) due to the variation of local noise events during the respective measurement periods. The noise spectra measured inside the room can therefore be expected to have an error of ±2dB(A).

After correction of the noise spectra measured inside the room, the overall attenuation of noise entering the room through the ventilation opening was 7dB(A). The attenuation of noise in the third octave bands to which the resonators were tuned ranged from 11dB to 22dB (±2dB(A)).

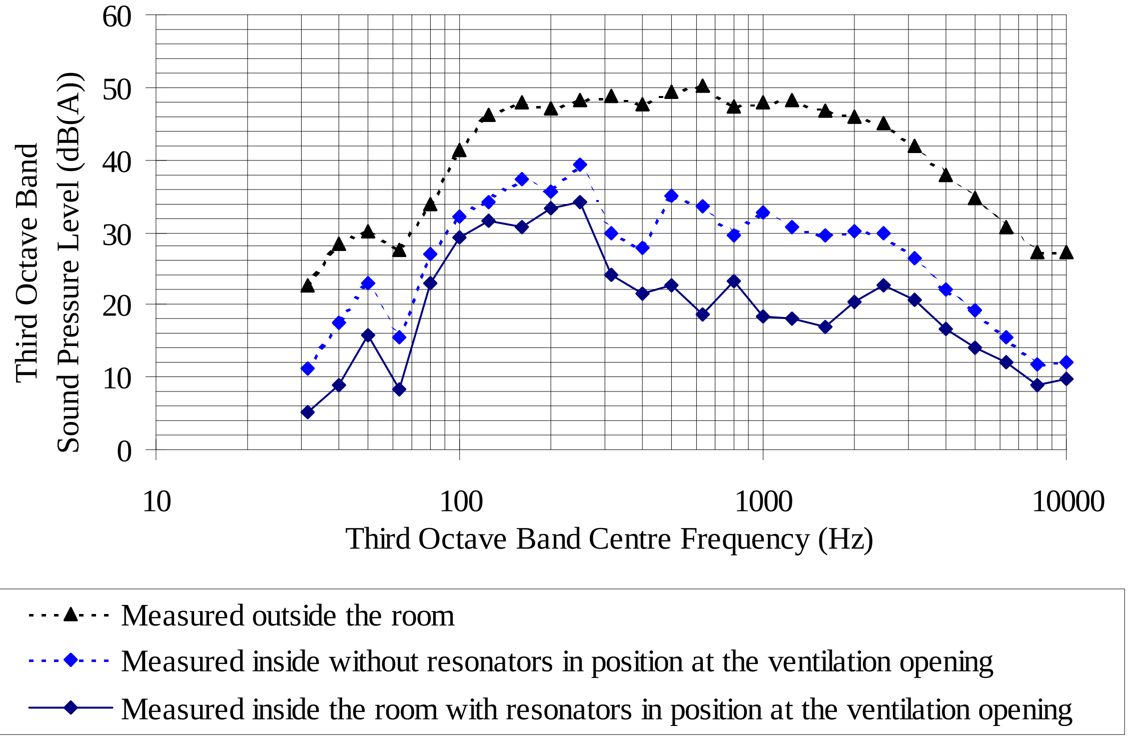

Figure 4: Measured Noise Spectra for Local Noise Events

The expected error of ±2dB(A) can be clearly observed by inspection of the noise spectra measured inside the room at frequencies below 400Hz (below the third octave band to which the lowest frequency resonator is tuned). Below this frequency, the spectra deviate slightly more than in measurements involving other noise sources.

2.4 CONCLUSION

Experimental results with the full scale resonator prototype have demonstrated that a system of quarter-wave resonators is capable of achieving significant levels of attenuation of noise entering buildings through ventilation openings.

Experiments using the “drive-by” of a medium size passenger vehicle as the noise source indicated significant attenuation of noise entering the room in the third octave bands to which the resonators were tuned. The overall reduction in internal noise level was 8dB(A). Attenuation levels in individual third octave bands of up to 20dB were achieved. Experiments using the motorcycle as a continuous noise source resulted in an overall reduction of internal noise level of 8dB(A). Experiments carried out using local traffic activities as the noise source also demonstrated the effective performance of the full scale resonator prototype. Despite the unavoidable difference in overall noise levels measured outside the room with and without the resonator system in position at the ventilation opening, because of the reliance on local traffic activities, the performance of the system was clearly reflected in the third octave bands to which the resonators were tuned. An overall reduction of internal noise level of 7dB(A) was achieved, with attenuation levels in individual third octave bands ranging from 11dB to 22dB. The calculated error in individual third octave bands due to the variation in measured spectra was ±2dB(A).

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