FINITE ELEMENT MODEL OF REAL FURNITURE IN SMALL ROOMS AT LOW FREQUENCIES

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Gustavo da S. V. de Melo[1]; Samir N. Y. Gerges [2]; Barry M. Gibbs[3]
[1] Computational Mechanics Group – Mechanical Engineering Department – UFPE
Av. Prof. Moraes Rêgo, 1235, Cidade Universitária, CEP 50670-901
Recife – PE
Brazil
Tel: 00 55 81 3271-8233
Fax: 00 55 81 3271-8232
E-mail: g.melo@ivillage.com

[2] Acoustics and Vibration Laboratory (LVA) – Mechanical Engineering Department – UFSC
Cx.P. 476
Florianópolis – SC
Brazil
E-mail: gerges@emc.ufsc.br

[3] Acoustics Research Unit (ARU) – The University of Liverpool
P.O. BOX 147, L69 3BX
Liverpool
England
E-mail: bmg@liv.ac.uk

ABSTRACT

Sound transmission (below 100 Hz) is an increasing contribution to nuisance, due to a proliferation of hi-fi systems, etc. A previously developed FE model has identified the need for an appropriate model of sound absorption in small-furnished rooms at low frequencies. Hence, a new model is used here to describe the relationship between sound absorption characteristics of internal surfaces of an enclosure, and its frequency response, for the interval 20 - 200 Hz. The numerical model is validated by comparison with measurements for a small reverberant chamber. Additionally, the effect of inserting real furniture and of furniture location is investigated.

INTRODUCTION

In the area of sound transmission in buildings, a recent emphasis has been given to the study of the audible frequencies below 100 Hz. This is due to the increase in sources of low frequency noise, e.g., proliferation in hi-fi systems of high power and enhanced bass response, increased use of mechanical services and devices, and increasing traffic noise break-in. A review of the main low frequency noise sources can be found in the work of Berglund et al [1]. There is a special concern about low frequency noise because of its efficient propagation in air, and because of the reduced ability of structures such as hearing protectors or separating walls to attenuate sound at these frequencies. Recent studies undertaken at the University of Liverpool [2,3], demonstrated that modal characteristics of pressure and vibration fields of adjacent rooms and separating wall, respectively, strongly influence the sound level difference between the rooms. Important outstanding issues to be addressed have been identified, e.g., the need for an appropriate model of sound absorption in small furnished rooms at low frequencies, and the consideration of modally reactive absorption due to the vibration of the walls.

In previous papers [4,5], the effect on the acoustic properties of an enclosure produced by an idealized element of furniture (the standard unit) has been investigated. Those works dealt, respectively, with solid and absorbent versions of the standard unit. In this paper, an investigation of the effect on low frequency room response of including real furniture is described. A single element of furniture, a large armchair, also was introduced in the numerical model, using the knowledge developed during the standard unit investigations.

CHOSEN ELEMENT OF FURNITURE

The element of furniture used in this work was a large armchair. It was selected as being representative of traditional furnishing, particularly in British homes. The chair was constructed of a timber frame, with steel spring seat supports. The frame and springs were covered with dense fibrous material, which in turn, was covered with low density fibre padding and cushions. The covering was a thick-woven textile. The overall dimensions were 0.85 m x 0.85 m x 0.85 m.

MEASUREMENT SYSTEM

As in [4,5], the empty room used as a reference was a small reverberant chamber of the Acoustics Research Unit of the University of Liverpool. The room dimensions are 5.78 m x 3.04 m x 4.24 m. Measurements were carried out with a loudspeaker and two microphones placed at corners of the enclosure, in order to excite and measure as many acoustic modes as possible. The measured frequency response (sound pressure level versus frequency) was obtained using a Maximum Length Sequence based system (MLSSA) in the Power Spectrum mode [6]. See [4] for a schematic of the experimental set-up. The armchair was positioned on three different locations within the room (centre of room floor, centre wall, and corner).

NUMERICAL MODEL

The procedure for numerically modelling the effect of introducing real furniture was similar to that adopted for the standard unit [3-5]. The preliminary measurements indicated a small change in response on introducing the chair, particularly below 100 Hz. This has practical significance. If furniture does not have a significant effect in this frequency region then it need not be included as a correction to the measured sound level difference between rooms.

A model of the armchair, including detail of its geometry, was introduced in the room numerical model, at the central floor position (see Fig. 1). The model was constructed using Sysnoise [7].

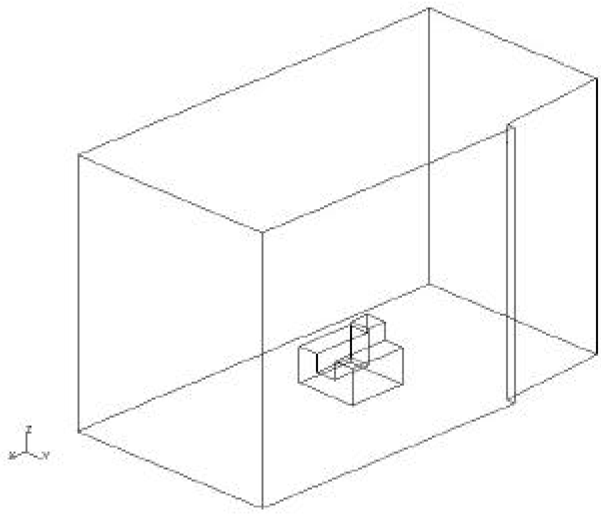

Figure 1 - Armchair at central floor position represented by the Chair model.

Constant absorption coefficients were applied to the room internal surfaces, and to the chair surfaces. As in [3-5], sound transmission through the modelled armchair was not included. This contradicts an approach by Estorff and Karstedt (2000) in a study of numerical representation of vehicle seats, where it was assumed that the transmission of sound waves through the seats had a significant effect on the sound pressure distribution in a car [8]. However, while this may be the case at higher frequencies (that work considered frequencies up to 600 Hz) and for smaller enclosures such as a car cabin, this was not observed during the investigations for the standard unit (see [4]), and, consequently, the same approach utilised previously was used in the investigation of real furniture.

A parametric survey was performed by prescribing different values of pure real admittance to the chair surfaces in the numerical model, corresponding to frequency invariant absorption coefficients of 30%, 50%, and 70%. The results were obtained for the chair placed at the centre wall position. Fig. 2 presents level differences obtained in 1/12th octave bands between measurement and predictions for Chair model with a = 30%, a = 50% and a = 70% assigned to the chair boundaries, respectively (a value of absorption coefficient of 2% was applied to the room boundaries). The figure shows that, despite a variation in a, the level difference was not significantly altered over the observed frequency range, particularly up to 37 Hz. Above this frequency, the results still presented strong similarities with a variation not larger than 4 dB (at 140 Hz) between the two extreme cases. In general the parametric survey indicates that the chair absorption is playing no significant role in modifying the room frequency response, and the intermediary absorption coefficient of 50% assigned to the chair boundaries was adopted in the investigation of the effect of the armchair on the reference FRF (empty room).

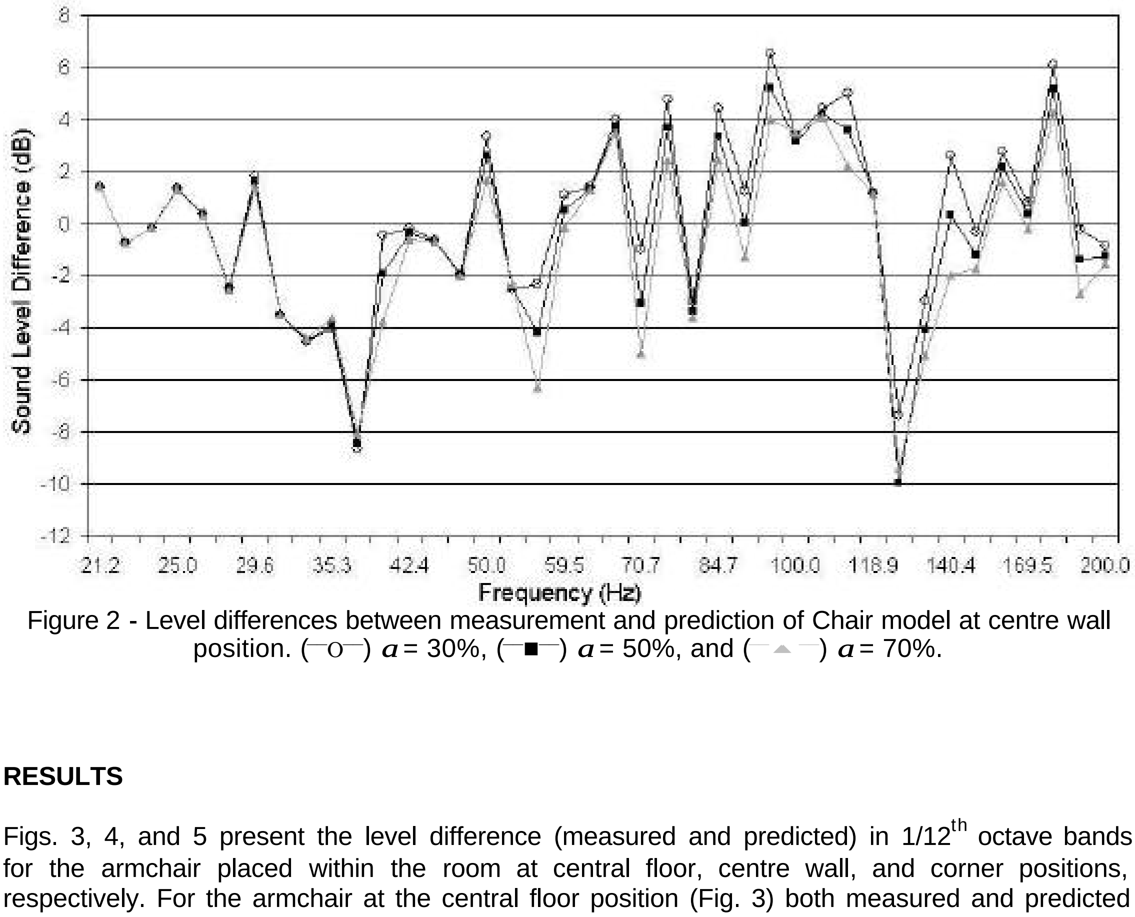

Figure 2 - Level differences between measurement and prediction of Chair model at centre wall position. (—o—) a = 30%, (—■—) a = 50%, and (—▲—) a = 70%.

RESULTS

Figs. 3, 4, and 5 present the level difference (measured and predicted) in 1/12th octave bands for the armchair placed within the room at central floor, centre wall, and corner positions, respectively. For the armchair at the central floor position (Fig. 3) both measured and predicted levels indicate that below 90 Hz the presence of the armchair has no significant effect on the room frequency response (considering the empty room results as a reference). For such interval the average level difference is 0 dB $\pm$1 dB. Above 90 Hz, the measured level difference presents a mean value of approximately 2 dB with a variation 0 dB to +5 dB. The predicted level difference did not present similar behaviour below 90 Hz, overestimating measurements by 2 dB on average. Above 90 Hz the numerical results matched measurements.

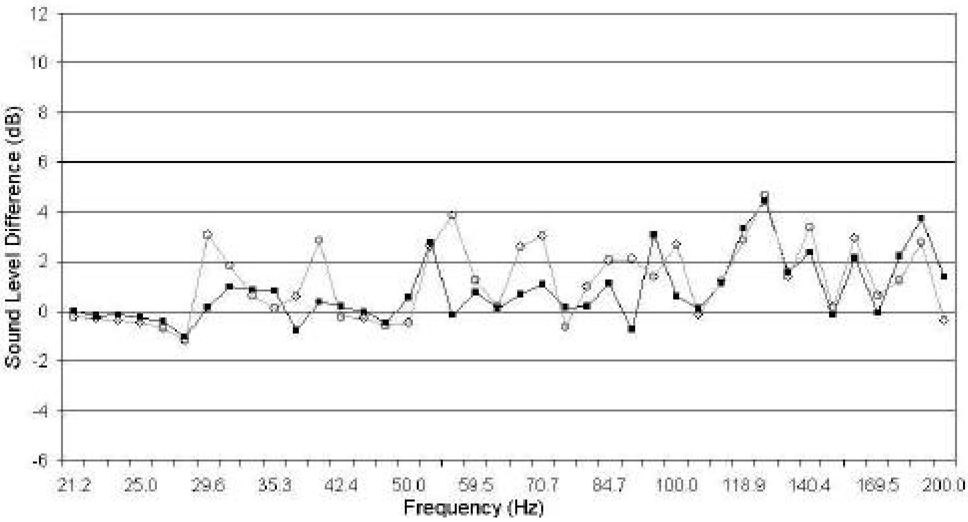

Figure 3 - Results for the armchair in the centre of the room floor: comparison between (—■—) measured and (—O—) predicted level differences in 1/12th octave bands.

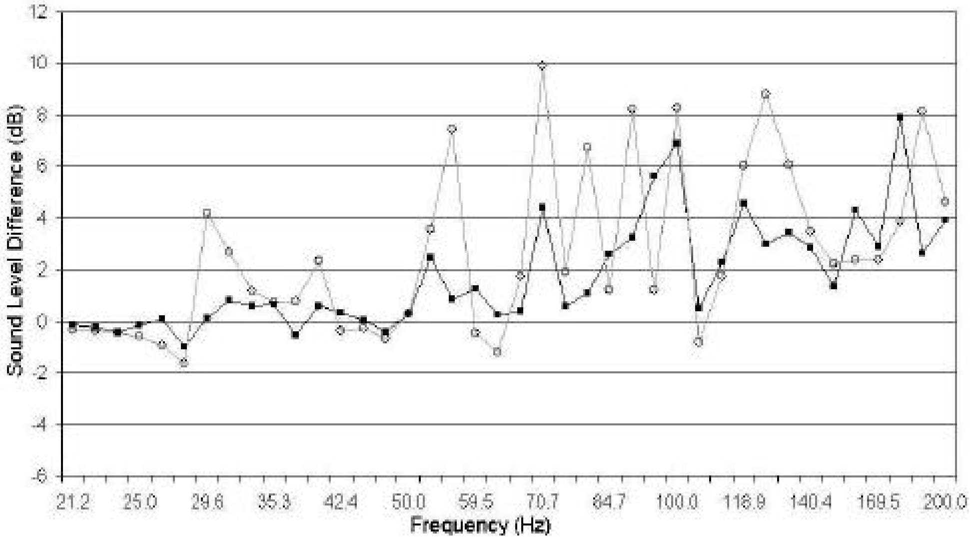

Figure 4 - Results for the armchair in the centre wall position: comparison between (—■—) measured and (—O—) predicted level differences in 1/12th octave bands.

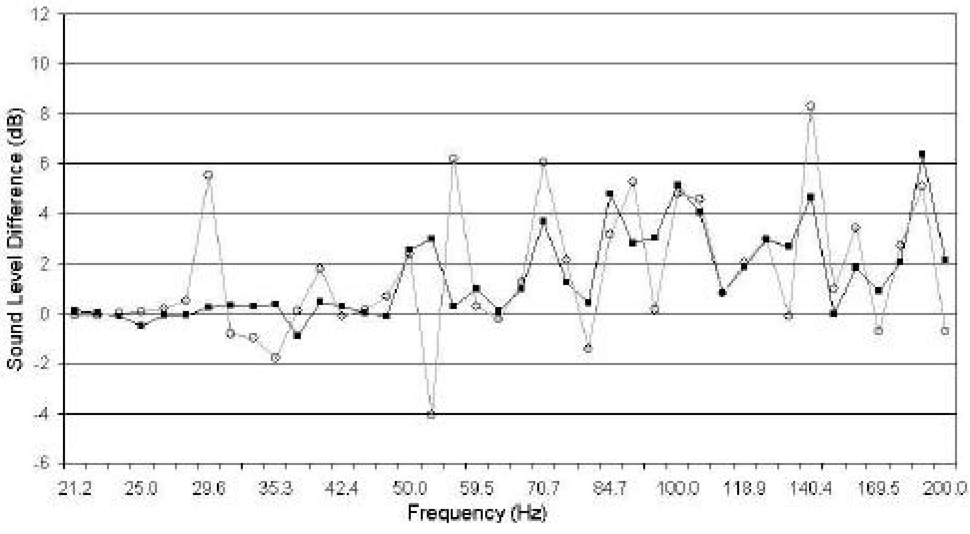

Figure 5 - Results for the armchair in the corner position: comparison between (—■—) measured and (—O—) predicted level differences in 1/12th octave bands.

The one-twelfth octave band results for the armchair in the centre wall position (Fig. 4) indicate an average level difference of 0 dB ±1 dB below 66 Hz. Above this frequency, the measured level difference is on average 3 dB with a variation 0 dB to +8 dB, whereas the predicted level difference is on average 4 dB with a variation -1 dB to +10 dB. The results for the armchair in the corner position (Fig. 5) show that the room response is altered above 50 Hz by an average value of 2 dB with a variation 0 dB to +6 dB for the measured level difference. In general, the predicted level difference was observed to match measurements.

Fig. 6 shows the effect of the armchair on the reference FRF, this time in one-third octave bands. The measured level differences to this resolution are on average 0 dB up to 63 Hz, 50 Hz, and 40 Hz for the chair placed in the central floor (Fig. 6-a), centre wall (Fig. 6-b), and corner position (Fig. 6-c), respectively. Fig. 6-a shows that above 63 Hz the average difference is 1.5 dB with a variation +1 dB to +2 dB when the armchair was centrally located. For the centre wall position, Fig. 6-b shows that above 50 Hz the average difference is 2.5 dB with a variation +2 dB to +4 dB. Fig. 6-c shows that when the chair was located in a room corner the average difference is of the order of 2 dB with a variation +1 dB to +3.5 dB. Independently of the chair position, the agreement between predicted and measured level differences was observed to improve with increasing frequency, and one possible reason for the observed discrepancies below 80 Hz is the used approach, in which a frequency invariant absorption coefficient of 50% was assigned to the chair boundaries. While such value may be representative of the chair absorption at frequencies above 100 Hz, it is likely to overestimate the absorption process at lower frequencies.

CONCLUSIONS

In this paper a description was given of an investigation of the effect of a real element of furniture on room frequency responses. From the previous investigations described in [3-5] it was assumed initially that, at low frequencies, real furniture would in general behave as solid objects covered by a layer of absorption. However, experimental results presented in this work indicate that the introduction of an armchair at different positions within a reference room does not significantly alter the room frequency response. This was also confirmed by numerical results, where a parametric survey showed that similar FRFs are obtained, even though the boundary absorption characteristics of the modelled chair were increased up to 117% of the initial value. Thus, a detailed modelling of an absorptive element of furniture within an enclosure is not justified. Also, independently of the armchair position, no significant eigenfrequency shift was observed in the results. However, as found for the investigations with the standard unit (see [4,5]), the centre wall position was found to be, once again, the most influential, despite the overall small effect. Because of the small measured effect of the introducing chair, it was not necessary to use the refined model of furniture absorption, described in [3]. Still, the refined model is available for rooms of large volume and more furniture such as in commercial situations.

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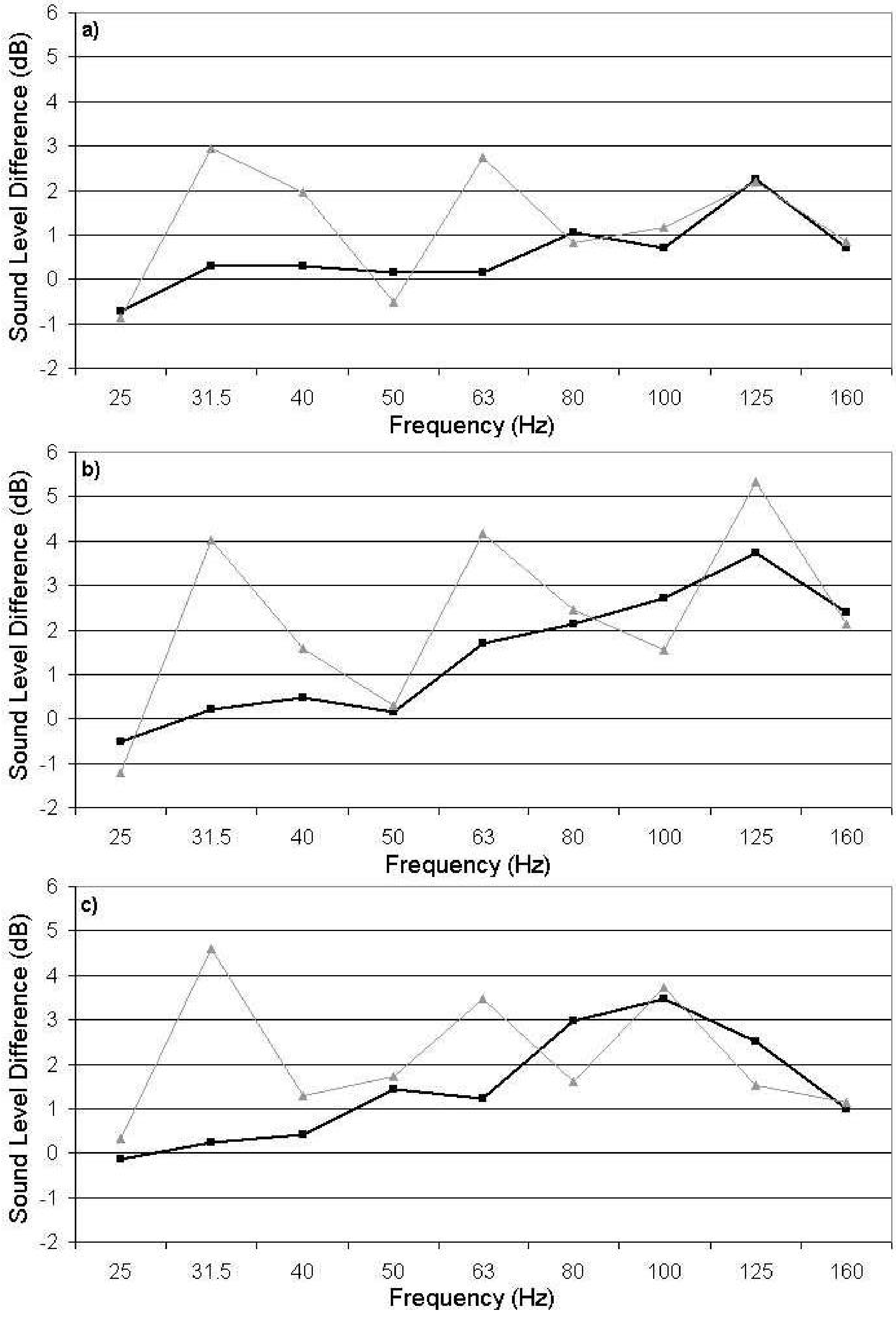

Figure 6 - Level difference (—■—) between measured values and (—▲—) between predicted values. Results shown in one-third octave bands. a) Central floor position, b) centre wall position, and c) corner position.