ACOUSTIC ISSUES AFFECTING OCCUPANTS OF AN OFFICE WITH A BREEAM RATING OF EXCELLENT

J De Avillez URS/Scott Wilson Acoustics, Nottingham, UK
A M Nash URS/Scott Wilson Acoustics, Cambridge, UK
N Conlan URS/Scott Wilson Acoustics, Nottingham, UK
R Hall URS/Scott Wilson Acoustics, London, UK
P J Shields URS/Scott Wilson Acoustics, Nottingham, UK

1 INTRODUCTION

Open-plan offices are becoming increasingly popular as they are considered flexible spaces facilitating team work and information sharing. However, they can lead to challenges in acoustic specification. Recent research [1, 2] suggests that productivity in open-plan offices can be compromised by acoustic issues, such as background noise and lack of speech privacy. Moreover, it has been established [3] that the strong sound reflections and the level of background noise can greatly disrupt the communication in a room. This is particularly salient in passive buildings where exposed heavyweight constructions and exposed soffits are used for controlling the indoor environment.

This paper presents the results of an acoustic investigation in an open-plan office building which achieved a BREEAM rating of 'Excellent' (referred to as the 'green office'). The green office is a naturally ventilated two-storey building; the ground and first floor spaces of which are connected through an open void in the floor. The void has had acoustic panels hung within it to provide additional sound absorption in a space which has exposed concrete soffits with carpet covering the majority of the floor area. This paper focuses on the first floor space which has a pitched ceiling with a height of up to 4.9m and a volume of approximately 900m^3 (not including the connected space on the ground floor).

The occupants of the building moved from a regular open-plan office building and some of the comments received about the acoustics of the new office related to:

a) lack of speech privacy, a need to speak in "quieter tones";
b) concentration affected when noise is high, hard to "block the noise out";
c) difficulty in communicating to a nearby colleague or on the telephone due to speech noise from people on the other side of the room.

Subjectively, one of the most obvious issues when entering the green office space was the audibility of individual voices around the office. Speech from a single person talking at a desk 14m away was clearly audible and distinguishable. During the visit to the building when more than one person talked, even at a distance of 14m, it was sometimes necessary to use a raised voice to communicate across a small table.

Using measurement and analysis of occupied noise levels, reverberation times and reflectograms, this paper attempts to explain why the occupants of the office experience issues with the acoustics. It compares these results with those from measurements undertaken in a more traditional open-plan office with a suspended acoustic ceiling, referred to as a 'typical' office.

2 CURRENT STANDARDS & GUIDANCE

Existing standards and guidance provide limited information on optimum reverberation times for open-plan offices. British Standard BS 8233 [4] and the British Council for Offices Guide to Specification (BCO) [5] both advise that the maximum affordable level of privacy between workstations in an open-plan environment will be achieved by having a low ceiling (up to 3m high), covered with a highly absorptive ceiling tile (average 0.9 over the frequency range 500-2000Hz) and with carpet having good sound-absorbent properties on the floor as a 'desirable floor finish'. BS 8233 also recommends that screening between workstations should be absorbent and at least 1.5m high.

A typical office space built according to the guidance has a calculated reverberation time of 0.5 seconds in the 500-2000Hz octave bands.

Most room acoustic guidance focuses on the 500-2000Hz octave bands due to the impact these frequencies have on speech intelligibility. However, other research has shown that reverberation times in the 1000-4000Hz octave bands are the most significant for speech intelligibility [6].

A desirable feature in offices is a steady level of background noise with no distinctive features, such as can be produced by building services. BS 8233 provides a design range of 45-50 dB $L_{Aeq,T}$ for an unoccupied open-plan office. The provision of a lower limit highlights the fact that some noise is desirable in an open-plan office to provide adequate privacy without causing disturbance.

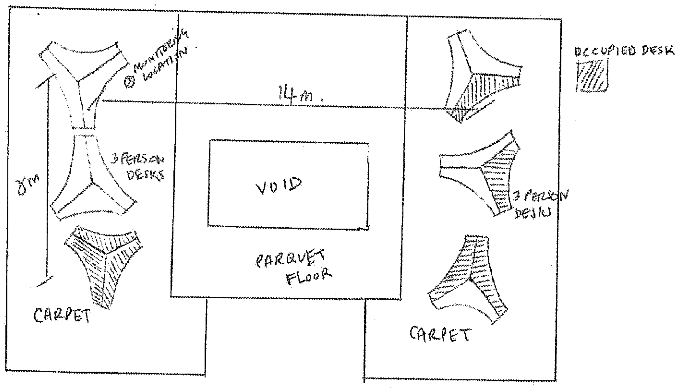
BREEAM for Offices 2008 [7] requires an indoor ambient noise level of 40-50 dB $L_{Aeq,T}$ for one credit for acoustics. This credit includes noise transmitted from outside as well as any internal noise sources such as building services.

There are no reverberation criteria in the BREEAM guide and there is no specific requirement under BREEAM to achieve any of the acoustic credits.

3 OCCUPIED AMBIENT NOISE LEVELS

Occupied ambient noise levels were measured at an empty pod of desks with occupied desks at approximately 8m and 14m away, see Figure 1. At the time of measuring seven people were working on the first floor, with around twenty more people working on the ground floor.

Figure 1 Approximate plan of first floor (not to scale)



Measurements were taken in contiguous 5-minute periods and Table 1 summarises the results for a 35-minute monitoring period.

Open-plan offices can have noise levels of 50-70 dB $L_{Aeq,T}$ [8]. Measured $L_{Aeq,5min}$ levels in the office ranged from 52.2-56.0 dB with $L_{A90,5min}$ values fairly constant at 50+/-1 dB, even though there were no building services. Therefore, it is considered that the overall noise levels alone do not explain why the occupants experience issues of both speech privacy and difficulty communicating.

Table 1 Occupied office noise levels in the green office

Period	Occupied Office Noise Levels (dB)		
	$L_{Aeq,5min}$	$L_{AFmax,}$	$L_{A90,5min}$
1	54.9	75.5	49.6
2	55.4	68.3	51.1
3	55.3	71.8	51.0
4	54.0	67.1	49.8
5	52.2	64.2	48.8
6	53.2	70.3	50.0
7	56.0	67.3	49.0

Activities in the green office included occasional phone calls and some normal level conversation between occupants. It was noted that although speech was the dominant noise source, other noise sources included typing, stapling and foot falls on the parquet floor. All appeared louder than would be expected and resulted in some high maximum levels.

It was noted that although the overall noise levels were not significantly high, the predominant noise source was speech. It is recognised that speech is the most disturbing sound in open-plan offices [9], and unlike a call centre where the high number of voice sources ideally creates a steady and generally unintelligible noise, it was possible to hear clear speech clearly from the few people that were present, throughout the green office. This created ambient levels which were dominated by fluctuating levels of speech noise and explains why occupants may have issues with speech privacy; further analysis is required to understand why difficulties with speech communication are not unusual.

Table 2 summarises the results of measurements taken in the typical office, which had a similar level of work activity to that in the green office, although the number of people working in the space was significantly greater than that in the green office. The monitoring location had line of sight to approximately 15 people (at a distance of 8-15m), and was shielded from a further 10 people (up to 15-20m away) by a filing cabinet.

The data show that, even though there are significantly more people in the typical office, undertaking similar work activities, steady $L_{Aeq,5min}$ levels of 46.0-49.0 dB are achieved. This is on average, 7 dB below that measured in the green office. The $L_{A90,5min}$ levels are 10 dB below that measured in the green office, and yet subjectively speech privacy was greater in the typical office. Subjectively the noise from speech in the typical office, which was audible and often intelligible, was much less intrusive.

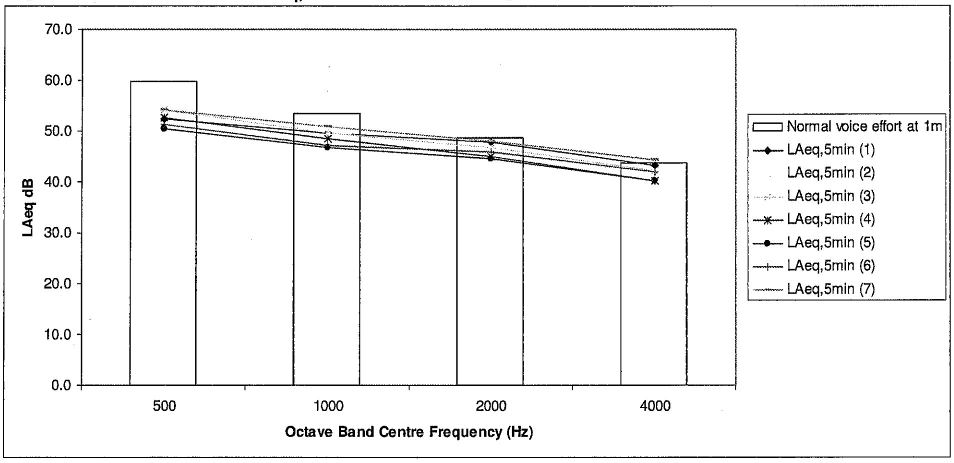
Table 2 Occupied office noise levels in the typical office

Period	Occupied Office Noise Levels (dB)		
	$L_{Aeq,5min}$	$L_{Amax,fast}$	$L_{A90,5min}$
1	48.3	63.9	40.8
2	47.0	65.3	39.9
3	46.0	69.7	40.0
4	49.0	64.6	43.0
5	48.1	64.9	41.6
6	46.1	63.9	40.1
7	48.8	64.0	42.8
8	48.7	62.7	42.0

4 SPECTRAL ANALYSIS

To try to understand further the reasons why occupants of the green office have concerns regarding speech privacy and occasionally difficulty communicating, spectral analysis has been undertaken on the $L_{Aeq,5min}$ data from the previous section. The noise levels in the 500-4000Hz octave bands has been compared to levels at 1m from a speaker when talking at a standardised 'normal voice effort' [10]; the results are shown Figure 2.

Figure 2 500-2000Hz $L_{Aeq,5min}$ levels in the green office

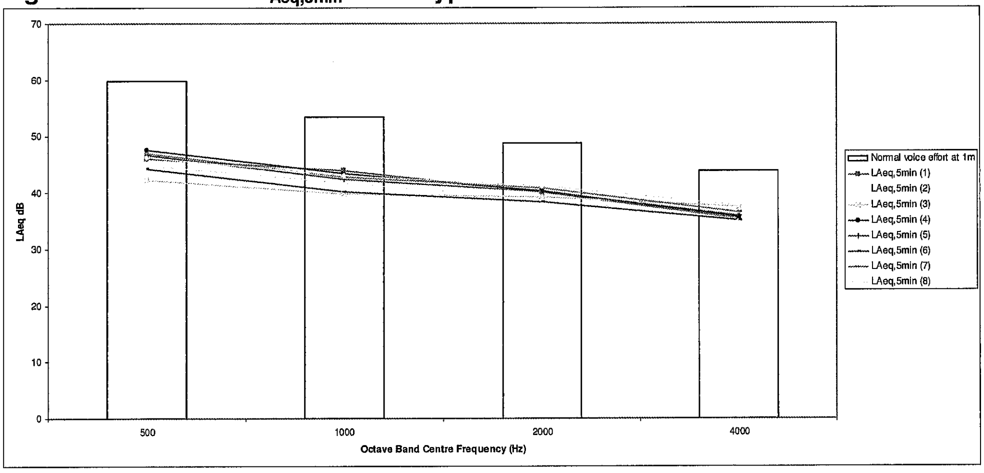


The results show that the average noise levels within the green office, which are dominated by speech noise, were generally within a few dB of the levels expected with normal voice effort at 1000Hz and 2000Hz. On a few occasions the normal voice effort levels at 4000Hz were marginally exceeded. As noted these octave bands have been shown to be most significant with regards to speech intelligibility, as this is the frequency region which contains the sounds of consonants. This may explain why occupants report occasional difficulty in communicating and hearing telephone conversations.

Our analysis is supported by other [11] who compared noise levels with NC curves and found that noise rated as NC45-50 may result in communication which requires 'normal voice 3-6ft; raised voice 6-12ft. Telephone use occasionally slightly difficult'. All the $L_{Aeq,5min}$ data falls into the NC45-50 range.

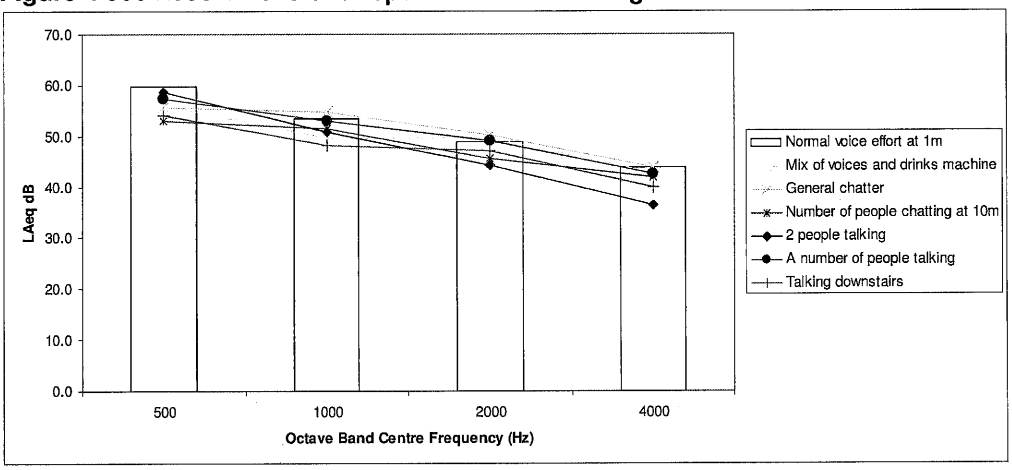
Occupied noise measurements taken in the typical office show that the $L_{Aeq,5min}$ levels were significantly lower than the levels quoted for normal voice effort in all octave bands. Although there were numerous conversations ongoing in the typical office, the noise levels generated did not cause any difficulty communicating for others, see Figure 3.

Figure 3 500-2000Hz $L_{Aeq,5min}$ in the typical office



As well as analysing the average levels, the octave band information has been isolated for number of speech events in the green office. Generally the speech occurred over a distance of 8-14m The results of this analysis shows that the speech events, which occur frequently, generate high noise levels at significant distance from the events which compete with the normal voice effort levels in the 1000-4000Hz octave bands, see Figure 4.

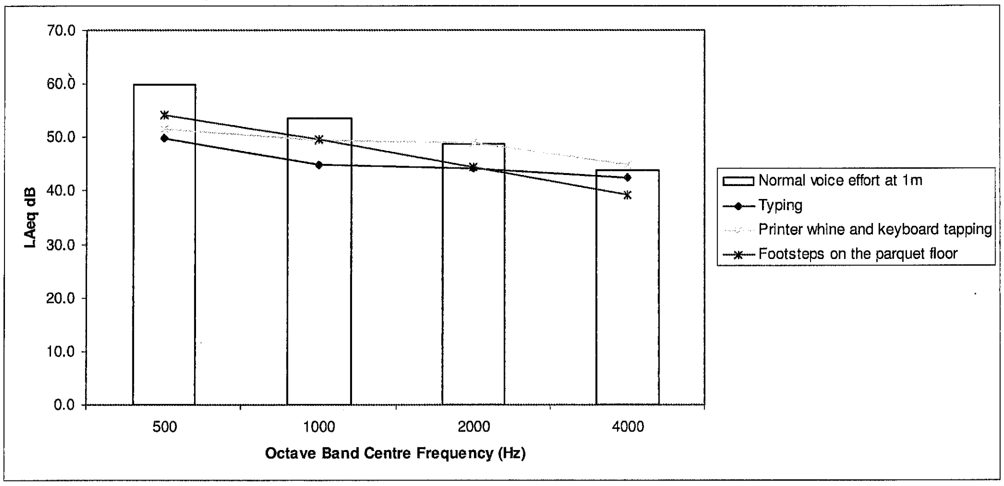
Figure 4 500-2000Hz levels for speech events in the green office



This may further explain the issue with privacy which, rather than being related to low background noise (as is often the case in buildings without building services), is related to lack of attenuation at high frequencies in the space. The human ear amplifies sound in the 1000-4000Hz frequency range, and this may explain why some people described the noise as "hard to block out", thus affecting concentration.

Other noise sources in the office generated significant noise levels, notably typing which was an almost continuous 'tapping' noise. Figure 5 shows the analysis of the noise levels measured where it is possible to see that a printer whine and typing noise have high levels and are similar, in level, to that of the normal voice effort levels at 2000Hz and 4000Hz.

Figure 5 500-2000Hz levels for other events in the green office



5 REVERBERATION

5.1 Octave Band Reverberation Times

Measurements of reverberation time, using the white noise interrupted sound method, were taken at a number of locations around the first floor green office. The results are shown in Table 3 for the 500-4000Hz octave bands.

Table 3 Measurements of reverberation time

Location	Reverberation Time (s) in Octave Band Centre Frequencies (Hz)			
	500	1000	2000	4000
Green office	1.3	1.3	1.2	1.0
Typical office	0.5	0.5	0.6	0.6

The reverberation times measured in the green office are greater than those recommended in BS 8233 for an open-plan office. The measured reverberation in the typical office is more in line with the recommended value. However, there is no reason why a suitable environment cannot be achieved with reverberation times greater than 0.5 seconds.

A significant issue is that the reverberation times in the high frequency octave bands are relatively long and that these frequencies are important in speech intelligibility. Applying absorption at high frequencies would reduce the reverberation time. It was considered that this would minimise the transmission of high frequency speech noise, improve speech privacy and reduce the likelihood of speech communication issues.

5.2 Early Reflections

In order to investigate the temporal distribution of the early reflections, reflectograms as proposed by [12] were used to examine the contribution to the perceived generated noise. A balloon burst was used as the excitation source. The reflectograms show the square of the sound pressure amplitudes (enhancing relevant reflections) in the first 300ms after the impulse. The reflectograms provide a useful representation of the impulse response showing the relative amplitude of the reflections and the time delays present.

Figure 6 and Figure 7 show the results of the test for the 1kHz and 2kHz octave bands in the green office with the receiver 14m from the source. Figure 8 and Figure 9 show the results of the same measurement undertaken in the typical office.

Figure 6 1kHz reflectogram measured in the green office

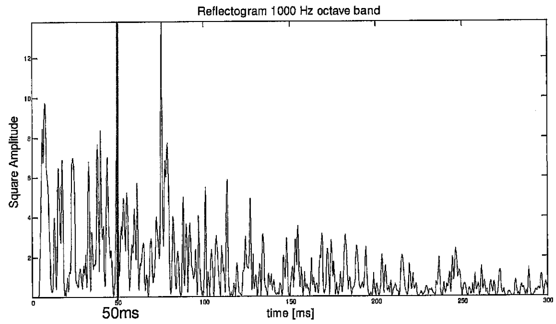


Figure 7 2kHz reflectogram measured in the green office

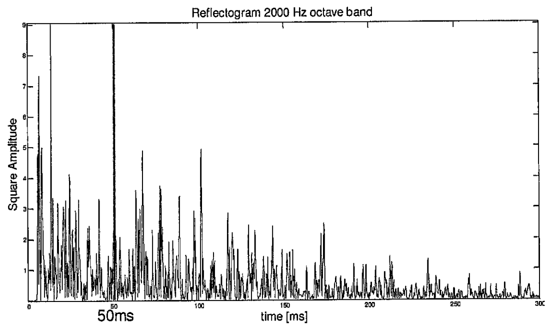


Figure 8 1kHz reflectogram measured in the typical office

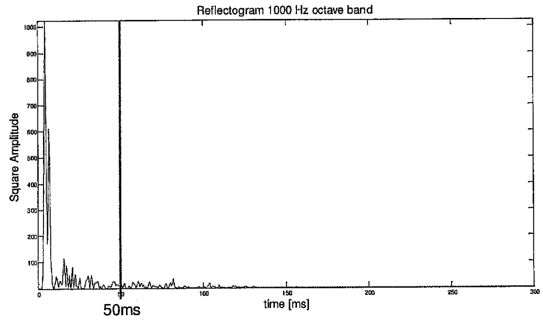
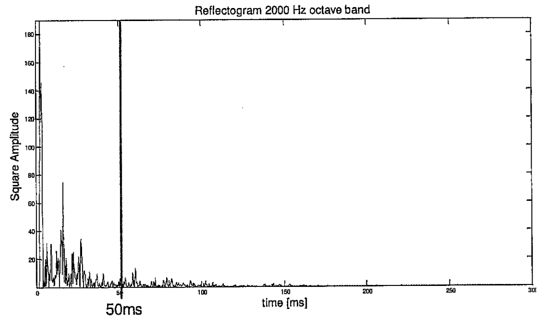


Figure 9 2kHz reflectogram measured in the typical office



Haas [13] demonstrated that our ear integrates the first 50ms as one single acoustic event. Therefore in the typical office, where the majority of energy is concentrated in the first 50ms, the ear will not perceive the reflections as distinct echoes. In the typical office the majority of the acoustic energy arrived at the receiver location within the first 50ms.

In the green office it is clear that there are strong reflections beyond the 50ms time window. The characteristics of these short echoes will especially impact on percussive noise events, such as footsteps and typing, making these events more noticeable to the occupants. The fact that there are strong early reflections at high frequencies increases the potential to affect communication due to the conflict between the percussive noisy events and the speech that is being conveyed (at the office or over the phone). The long reverberation time means that speech is not always intelligible, but it remains the dominant source of noise in the space.

It is considered that it is a lack of high frequency absorption is the fundamental reason that the occupants of the office experience noise levels which they consider affects their concentration and ability to communicate. It is also considered that this is the main factor in the occupants feeling there is limited speech privacy.

BREEAM credits are intended to promote low carbon use and sustainability. However if acoustic conditions are such that occupants do not find the building suitable, then the building is not sustainable. This raises the question that perhaps the acoustic credits should be mandatory, and should include reverberation requirements and guidance, to ensure the building is fit for purpose.

6 CONCLUSIONS

This paper set out to find potential reasons for occupants of an office complaining of 'limited speech privacy', 'affected concentration' and 'difficulty communicating. This paper has provided possible reasons for the issues described, which can be summarised as follows:

a) issues surrounding speech privacy do not appear to be directly related to a low level of background noise, but are likely due to the strong early reflections at high frequencies meaning normal level conversation can be heard throughout the office space;
b) concentration may be affected due to relatively high occupied noise levels which are predominantly speech noise, with significant high frequency content; and
c) difficulties experienced in communicating are likely to be caused by a lack of high frequency absorption which can result in normal vocal effort being masked by a number of people talking at a distance of 14m.

This paper has presented a case where the focus on achieving BREEAM credits has resulted in acoustics which occupants from a typical office environment can find challenging.

BREEAM for Offices acoustic credits do not provide any requirements for reverberation time, and currently 'Excellent' can be achieved without the need to achieve any acoustic credits. The data presented put forward an argument for a minimum range of specific credits needing to be achieved before an award of Excellent can be given. It is recommended that, for offices such as this, necessary credits should include acoustics.

7 REFERENCES

1. Annu Haapakangas, Riikka Helenius, Esko Keskinen, Valtteri Hongisto, Perceived acoustic environment, work performance and well-being -survey results from Finnish offices, Performance: 9th International Congress on Noise as a Public Health Problem (ICBEN) 2008, Foxwoods, CT
2. Akihiro Kawamura, Shin-ichi Tanabe, Naoe Nishihara, Masaoki Haneda and Masanori Ueki, Evaluation Method for Effects of Improvement of Indoor Environmental Quality on Productivity; Proceedings of Clima 2007 WellBeing Indoors
3. G. A. Soulodre, N. Popplewell, J. S. Bradley; (1989), Combined effects of early refelections and background noise on speech intelligibility. Journal of Sound and Vibration (1989) 135(l), 123-133
4. BS8233: 1999 Sound insulation and noise reduction for buildings – Code of practice
5. British Council for Offices Best Practice in the Specification of Offices – Guide to Specification 2009
6. Herman J.M. Steeneken, Tammo Houtgast; Mutual dependence of the octave-band weights in predicting speech intelligibility; Speech Communication 28 (1999) 109-123
7. BRE Environmental and Sustainability Standard, BES 5055: Issue 3.0, BREEAM Offices 2008 Assessors Manual,
8. BS 5839-8: 1998 Fire detection and fire alarm systems for buildings — Part 8: Code of practice for the design, installation, commissioning and maintenance of voice alarm systems
9. Erling Nilsson, Björn Hellström, Room Acoustic Design in Open-Plan Offices 10ème Congrès Français d'Acoustique, Lyon 12-16 April 2010
10. American National Standards Institute, American National Standard Methods for the Calculation of the Speech Intelligibility Index (ANSI S3.79-draft Version 3.1).
11. *www.wyle.com/PDFs/archive/ANE-6.pdf*
12. Heinrich Kuttruff (2009) Room Acoustics spon press, London & New York
13. H. Haas, The influence of a single echo on the audibility of speech,1972 The Journal of the Audio Engineering Society 20(2), 146-158.