CASE STUDY: ACOUSTICS OF AN INDOOR SHOOTING RANGE

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Abstract
Buildings and indoor spaces should be designed to meet requirements related to their use. This is even more important when there are noise sources inside that produce very high sound levels. This paper presents a case study on the acoustic issues of an indoor shooting range. The shooting range is located inside a multi-story building. There are different facilities in the building including offices, laboratories and a cafeteria. The objective of the study was to assess the acoustics of the shooting range and the possible nuisance caused to nearby premises. A range of measurements were taken. The reverberation time inside the shooting range was measured to see if the coating materials play a part in decreasing the sound pressure levels. Sound levels produced inside the shooting range by the guns were measured to evaluate the sound pressure levels that shooters are exposed and to check if the ear muffs used are suitable. The airborne sound insulation between the shooting range and a nearby office was measured, as were the sound pressure levels produced inside the office by gunshots, in order to understand to what extent the noise generated in the shooting range pollutes the neighboring areas.

Keywords: shooting range noise, airborne sound insulation, reverberation time, sound pressure levels.

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1 Introduction

Buildings and their rooms or areas need to be designed for their intended use. The space and the quality of the environment should be appropriate to their occupants. Indoor shooting ranges, for military purposes or leisure, exist because they allow protection against atmospheric agents and can be used at any time and under controlled environmental conditions.

The major problems related to such spaces could be poor environmental and occupational control resulting in adverse working conditions. Lead air pollution and noise are among the factors that adversely affect health. The scarcity of information and specific regulations on shooting ranges, combined with confidentiality issues, constitute an obstacle to the design of such facilities. The information available to the public is mostly from the USA, which is one of the countries with the most references in this area because the defense industry has developed facilities alongside those of civil society. In Portugal Regulatory Decree 6/2010 of 28 December [1] sets out the rules for licensing shooting ranges and complexes for firearms practice. This document states that such amenities must comply with the requirements of the General Regulation on Noise, approved by Decree-Law 9/2007 of

January 17 [2]. However, the rules stated in [1] do not apply to installations belonging to the armed forces and the security services. The regulations concerning firing ranges applicable to the army are administrative regulation RAD-38-1 and technical manual MT-38-2 [3]. The occupational risk of exposure to noise is regulated by the Decree-Law 182/2006 of September 6 [4]. Shooting ranges can be installed in purpose-built or multifunctional buildings. In the latter case, the sound insulation should be planned at the design stage according to the sound insulation principles commonly used in buildings. In Portugal, reference [2] refers to Decree-Law 96/2008 of June 9 [5] with respect to sound insulation in buildings. However, shooting ranges within buildings do not have framework in this last document.

In this paper we report a study on an indoor shooting range installed in a multifunctional building. The study comprised some acoustical measurements, which were taken with the permission of the management of the building (in 2014). The measurements were relevant to determining noise conditions inside the shooting range and to assessing the sound levels in offices near the shooting range. Two measurements were taken to characterize the shooting range: the reverberation time, and the sound pressure levels produced by a team of shooters inside the shooting range. The airborne sound insulation, and the sound levels inside the office generated by the shooters team were all registered, too, to characterize the building in general.

2 Experimental characterization

The shooting range is about 25 m long and 15 m wide and has a volume of around 1107 m^3. All the surfaces are covered with materials to protect users from bullet ricochets, rebounds and fragmentation.

The reverberation times were measured to find out if the coating materials contribute to reducing indoor sound levels. The measurements were taken in accordance with NP EN ISO 3382-2:2011 standard [6]. The equipment used during measurements was a sound source OmniPower 4292 and a sound level meter 2260, both by Bruel & Kjaer. The test setup includes four sound source positions and twelve microphone positions. Three decays were measured at each point.

To assess the noise exposure levels that users are subjected to, a team of shooters (potential users) fired the type of weapons planned to be used and this provided the noise source. Measurements were taken with the sound level meter over several periods in a total of 70 minutes. The noise registered was taken to be representative of the noise produced during the operation of the shooting range. Those measurements were used to calculate the sound exposure level to which shooters are subjected, and the results compared with legal limits, taking into account the ear muffs used.

Since the shooting range is part of a building where there are areas whose occupants need to concentrate and require quiet, it is important to evaluate the airborne sound insulation between the two areas. Thus, the sound insulation was measured between the shooting range and an office in the upper floor with a volume of 35m^3. The office is located above the entrance of the shooting range. The test was carried out in accordance with NP EN ISO 140-4:2009 [7] and NP EN ISO 140-14 [8]. The sound field was again generated by OmniPower 4292 sound source equipment and the sound pressure levels were again measured sound 2260 level meters (both by Bruel & Kjaer). The test layout had two sound source positions and five microphone positions in the shooting range (source room), and five microphone positions in the office (receiving room) in the upper floor. The reverberation time in the receiving room was measured at one sound source position and three microphone positions, with two decays per position. The weighted standardized level difference, $D_{nT,w}$, was then calculated following standard ISO 717-1:2013 [9] procedure.

The sound levels in the office generated by the gunshots in the shooting range were also measured to evaluate the noise in the office during the shooting exercises.

Different noise weighting curves for background noise were used to rate the noise heard in the office, since none of those curves is specific for this type of noise. The ambient noise was estimated based on the rating values.

3 Presentation and analysis of results

3.1 Reverberation time in the shooting range

Table 1 shows the results of the reverberation time, for octave band frequencies from 125 Hz to 4000 Hz, in the shooting range.
The reverberation time obtained is quite low, given the relatively large volume of the shooting range. The coating material applied to prevent damage from ricocheting bullets has good sound absorption properties, which helps decrease of sound levels inside the shooting range. The average value for octave bands of 500 Hz, 1000 Hz and 2000 Hz is 0.77 s. This parameter is used to assess compliance with established requirements for acoustic spaces in buildings under Decree-Law 96/2008 [5]. Although the type of area studied (shooting range) is not one of those specified in this Decree-Law, the value obtained meets, for example, the requirements of an auditorium with the same volume as the shooting range.

Table 1 – Reverberation time in the shooting range.

Frequency (Hz)	Reverberation time (s)
125	1.32
250	1.08
500	0.98
1000	0.73
2000	0.60
4000	0.55

3.2 Airborne sound insulation

Airborne sound insulation measured according to NP EN ISO 140-4 [7] and NP EN ISO 140-14 [8] leads to a weighted standardized level difference $D_{nT,w}\left(C;\, C_{tr}\right) = 66(-2;-5)$. However, for higher frequencies the sound levels in the receiving room are very low, close to the background noise, and the values of sound insulation appear as lower bound values. It seems that the source does not have enough power to determine the real sound insulation in this case. The curve of airborne sound insulation and the ISO 717-1 reference curve are displayed in Figure 1.
The airborne sound insulation was estimated using the gunshot as sound source and measuring the sound levels in the shooting range and in the receiving room. The spectrum of the source has higher amplitudes than that of the OmniPower 4292 sound source (B & K), especially at high frequencies, as seen in Figure 2. The value calculated for the sound insulation single value, equivalent to $D_{nT,w}$, is around 68 dB (higher than that obtained in the test). The levels measured in the receiving room with this source are always higher than the background noise.

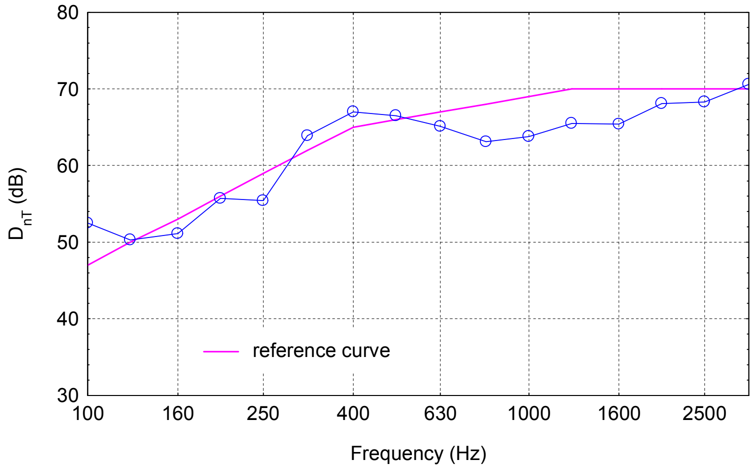

Figure 1 – Reference curve and D_{nT} values between the shooting range and the office.

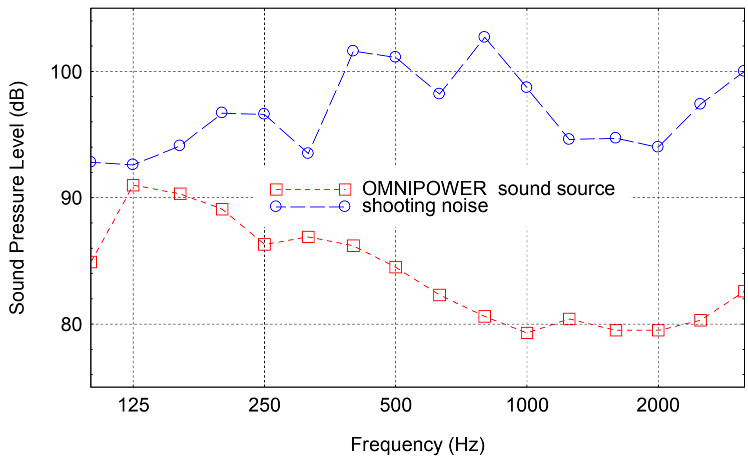

Figure 2 – Average sound pressure levels in the source room with the OmniPower sound source and with the gunshot noise.

3.3 Sound levels inside the shooting range

Table 2 shows the A-weighted sound levels generated by the shooting exercise in the shooting range. The noise exposure of the users has been evaluated for the person who spends most time inside the shooting range, the instructor.

A plausible scenario for an instructor's typical working day has been simulated. Table 3 presents the timetable and expected sound levels during the specified tasks. The first hour involves preparing the shooting range, including conversation between instructor and shooters to organize exercises scheme. The cleaning of the shooting range includes the noise of the ventilation system needed to clean the air. The sound pressure levels of the training period correspond to the levels measured in the tests.

The equivalent sound level is $L_{Aeq} = 107.2$ dB (A). For an 8-hour working day, the sound levels without ear muffs correspond to $L_{Ex,8h} = 107.2$ dB(A) and a value of $\mathrm{L_{Cpeak}} = 133.6\,\mathrm{dB\,(C)}$. According Decree-Law 182/2006 of September 6 [4] the value of $L_{Ex,8h} = 107.2$ exceeds one of the Upper Action

Values ($L_{EX,8h} = \overline{L}_{EX,8h} = 85$ dB(A), $L_{\text{Cpeak}} = 137$ dB (C), without ear protectors) which requires taking certain preventive measures, including ensuring the use of ear protectors.

Table 2 – Sound levels measured in the shooting range.

Frequency (Hz)	L_{Aeq} [dB(A)]
63	77.6
125	81.9
250	92.0
500	102.1
1000	104.6
2000	101.6
4000	100.0
8000	95.8

Table 3 – Timetable and sound levels.

Time	Tasks	L_{Aeq} [dB(A)]
9:00-10:00	Preparation	65.0
10:00-12:30	Training	108.8
14:00-17:00	Training	108.8
17:00-18:30	Cleaning	80.0

During the shooting exercise the team of shooters used three different hearing protectors, HP1, HP2, HP3.
When calculating the exposure limits it was assumed that the shooters would only use ear muffs during the training period. The levels with the protectors were calculated for each frequency, taking into account the average attenuation of the muffs and the standard deviation, according to the expression

$$L_n = L_{Aeq,f,Tk} - M_f + 2s_f, \tag{1}$$

where M_f is the average sound attenuation and s_f is the standard deviation of the sound attenuation and $L_{Aeq,f,Tk}$ is the A-weighted sound level measured for that task. The results obtained for the height hours are given in Table 4.

Table 4 – Daily personal noise exposure for the scenario considered (with hearing protection during the training period).

Duration (h) Task	1 Preparation	5.5 Training	1.5 Cleaning	- -
-	L_{Aeq} (dB(A))	$L_{Aeq,Tk,effect}$ (dB(A))	L_{Aeq}(dB(A))	$L_{Ex,8h}$ dB(A)
HP1	65.0	88.3	80.0	86.8
HP2	65.0	77.2	80.0	77.4
HP3	65.0	86.4	80.0	85.0

The exposure limit values according reference [4] are 87 dB (A) (with hearing protection) and L_{Cpeak} 140 dB(C). In this scenario, the exposure limit of 87 dB (A) is not exceeded with any of the ear muffs. However, HP2 ear muffs were recommended because the levels of noise exposure with the other protectors were closer to the limit values.

3.4 Sound levels inside the office

The use of a space for a specific purpose in practice requires the specification of the maximum tolerable background noise level. In Portugal, however, the legal requirement is not the maximum sound level but the levels of sound insulation.

The specification of A-weighted sound levels is the simplest method to specify the maximum tolerable background noise, since it correlates well with the subjective response to noise. However, noise weighting curves such as noise rating (NR), noise criteria (NC), balanced noise criteria (NCB) curves and room criteria (RC) curves [10, 11] are often used for indoor noise and for situations where noise control is required.

The background sound pressure levels (in dB) registered in the working room (office), with and without the gunshot noise, are presented in Figure 3. The corresponding A-weighted equivalent sound pressure levels are displayed in Table 5. In the literature, the recommended sound levels for offices are around 35 dB(A) [11, 12] and the maximum acceptable sound levels are around 48 dB (A) [13].

The sound levels registered when there is no shooting are lower than those reference values. However, with the sound of firearms the sound level exceeds the recommended level.

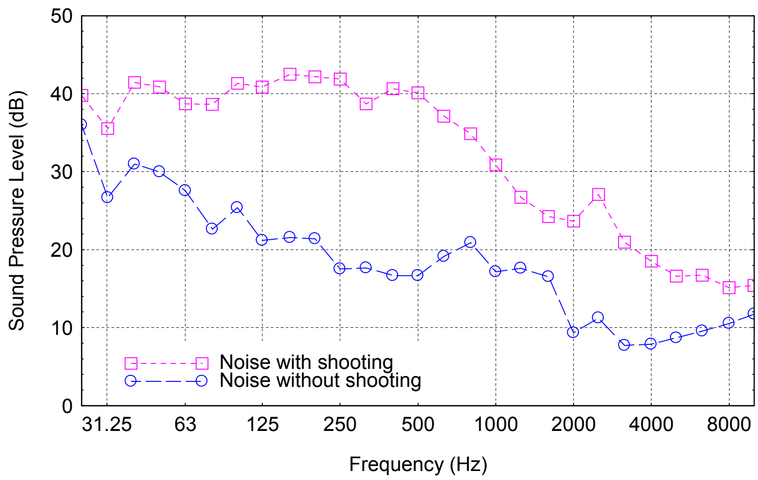

Figure 3 – Sound pressure levels inside the receiving room (office) with and without gunshot noise.

There are no weighting curves for rating gunshot noise, although noise weighting curves have been tested such as NR, NC, NCB and RC. The single noise rating values are also presented in Table 5.

Table 5 – Sound levels and single values of noise rating weighting curves in the office.

	Background noise	Noise of shooting
L_{Aeq}(dB(A))	27.0	44.0
NR	41	24
NC	22	39
RC	21	37
NCB	19	34

The maximum acceptable values for offices are in reference [13] 35 NC and 35 RC. Reference [12] presents a table (Table 6) to compare noise weighting curves with dB(A) specifications and allow rating of the ambient noise. According this table, ambient noise without shooting can be considered very quiet while with shooting it can be considered between quiet and moderately noisy. However, peoples' attitude and tolerance to noise vary and it can be judged differently. It is expected that the users of the offices in or near the room where the measurements were carried out can detect the sound of gunfire in the shooting range, since this type of sound was clearly identified by the technicians who carried out the measurements.

Table 6 – Comparison of ambient level criteria [12].

	Specification			
dB(A)	NR	NC	NCB	Comment
25-30	20	20	20	Very quiet
30-35	25	25	25	
35-40	30	30	30	Quiet
40-45	35	35	35	
45-50	40	40	40	Moderately noisy
50-55	45	45	45	
55-60	50	50	50	Noisy
60-65	55	55	55	
65-70	60	60	60	Very noisy

4 Conclusions

This paper presents a case study on the acoustic issues of a shooting range. Acoustic measurements were taken to characterize the acoustic environment. The reverberation time measured in the shooting range is relatively low considering the volume of the shooting range, which means that the coating material has good sound absorption and contributes to the reduction of the sound levels.

The airborne sound insulation between the shooting range and the nearby office is high for an ordinary, non-specialized building. Although the sound pressure levels are not high in the office, the sound of shooting was quite noticeable during measurement taking. Despite the high values of airborne sound insulation, it could perhaps be higher for this situation. According to reference [12] the ambient could be classified between "quiet" and "moderately noisy".

As expected, according to Portuguese legislation, the shooters should use ear protectors when training in the shooting range. The muffs they use are good enough to remain below the sound exposure limits, however hearing protection HP2 is the best. In conclusion, the design and construction of a shooting range inside a multifunctional building requires special care. Besides the concerns related to the exposure of users to pollutants (noise, lead, etc.) the location of the shooting range inside the building is very important, as are the requirements for sound insulation between it and the other areas in the building.

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