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Sound and Noise in Shopping Malls

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ABSTRACT
This study characterizes the interior acoustics in four shopping malls in Portugal (each with a total area from 12,000 to 72,000 m^2) by in situ measurements of objective acoustic parameters (reverberation time *RT*, *LAeq* background noise levels and Rapid Speech Transmission Index *RASTI*) with and without occupation (in corridors and food courts), comparing those with proposed ideal values and basically evaluating the influence that the rooms surrounding features have on the measured results. Results show average *RT* values between 1.7 and 3.2 s and *LAeq* (with occupancy) between 67 and 70 dB.

1 INTRODUCTION
Shopping centers are frequented by numerous people not only for shopping activities but also for social and leisure purposes. The considerable size of some of the malls, with large circulation spaces, high ceilings and generally a large food court where large numbers of people gather, leads to elevated background noise and reverberation time values, which result in poor speech intelligibility in a noisy space.

2 SAMPLE
The four shopping malls chosen as case studies were: *Arrábida Shopping*, *Via Catarina*, *Norte Shopping* and *Dolce Vita Porto* in Portugal (Table 1). For reasons of confidentiality and at the request of one of the managing bodies of these spaces they will be assigned letters *A*, *B*, *C* and *D* without any order or correspondence in particular.

Table 1: Main data of the tested malls[1].

Data	*Arrábida Shopping*	*Via Catarina*	*Norte Shopping*	*Dolce Vita Porto*
Localization (town)	V. N. Gaia	Porto	Matosinhos	Porto
Opening date	1996	1996	1998	2005
Total area (m^2)	64,400	11,700	71,740	38,360
Number of shops	190	93	267	129
N^o. of commercial floors	3	4	2	5

3. ACOUSTIC CHARACTERIZATION

3.1 Methodology and ideal values

The evaluation of the acoustic objective parameters was conducted in two situations:

- "Without occupation" in the malls (measurements done after the night closure of the shopping center) where it was measured the reverberation time (*RT*) and the background noise (*BN*) in the food court and on a “reference floor” (the lower level of the mall), and *RASTI* only at the food court;
- “With occupation” (during the normal operation of the shopping centers) where the *BN* in the food court was measured.

The purpose of this study is to investigate the values for these parameters, their variability and suitability for acoustic comfort in this type of space. Table 2 shows a tentative proposal for ideal values in these spaces in order to later confront with the measured values.

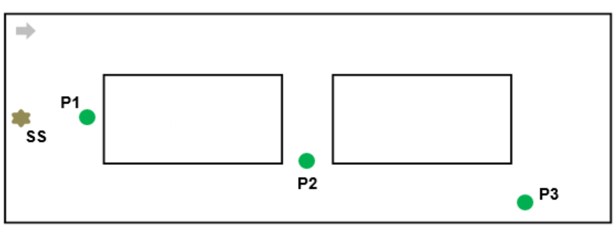
Table 2: Proposed ideal values of reverberation time, background noise and RASTI in shopping centers.

Acoustic parameters	Ideal values
Reverberation Time (RT)	1.1 to 1.3 s [avg. 500, 1k, 2k Hz]
Background Noise, with occupation (L_{Aeq})	≤ 55 dB
Rapid Speech Transmission Index (RASTI)	≥ 0.45

3.2 Reverberation Time (RT)

The measurements of Reverberation Time (*RT*) were done after the closure of the shopping centers, in the food court and on the “reference floor”, on a non-occupation mode so, no sound sources other than the intrinsic and permanent of the space itself were present (for example: cleaning operations). The measurements were made with a B&K sound source (SS) at a single point and a B&K 2260 sound level meter supported on a tripod, in three different positions, at a height of about 1.40 m (Fig. 1). The sound level meter made two readings in each position, obtaining the arithmetic mean of the measurements.

The Figures 3 and 4 show the variation of the *RT* values respectively in the "reference floor" and in the food court, in the four cases. Figure 3 shows that, on the reference floor, the more appropriate mean *RT* corresponds to mall *C*. This situation is related to its spatial configuration, resembling a long corridor with absorbent materials on some surrounding surfaces, therefore a less reverberant space. Moreover, the highest reverberant building on high frequency refers to the mall *A* (especially on 500 to 2k Hz) with a peak of 3.4 s at 1k Hz. This becomes worrying because it is in these frequency bands that the principal domain of the word is and can thus interfere negatively on speech intelligibility.



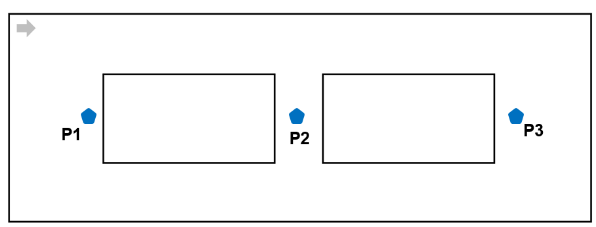


Figure 1 (left): *General outline of the spatial configuration of the studied area for RT, sound source location (SS) and measuring positions (P1 to P3).*

Figure 2 (right): *General outline of the spatial configuration of the studied area for background noise (measuring positions P1 to P3).*

In the food courts is verified (Fig. 4) that the shorter mean *RT* (and the most appropriate) corresponds again to mall *C*. This is due to sound absorption on some of the surrounding surfaces (absorbent perforated ceiling panels and textile canvas at the entrance of the restaurants) as well as its reduced height in comparison with the other cases, important for reducing reflections' delays and reverberation. Shopping centers *A* and *B* were the most reverberant, because they have high ceilings, greater volume and *B* even has a glass ceiling that has a very low sound absorption at high frequencies.

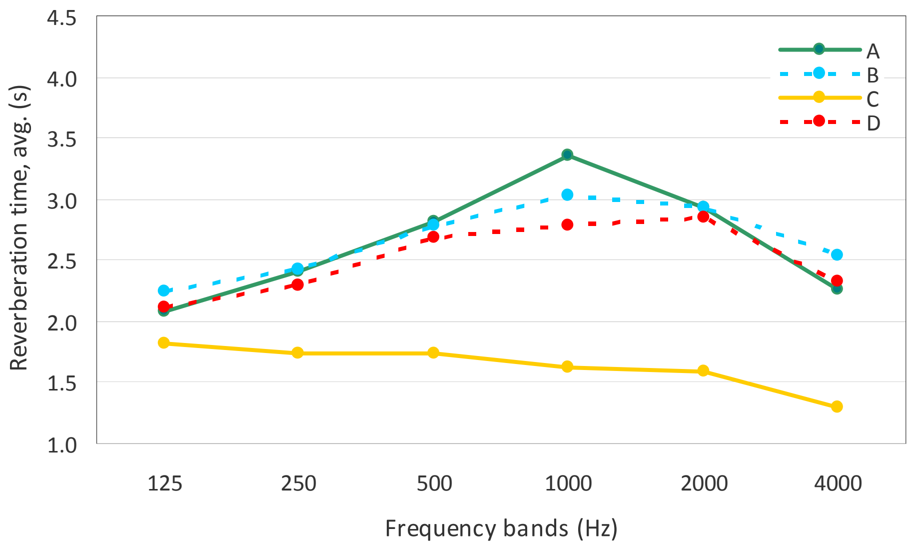


Figure 3: *Average RT variation on the reference floor (lower level), in shopping centers A, B, C and D*[1].

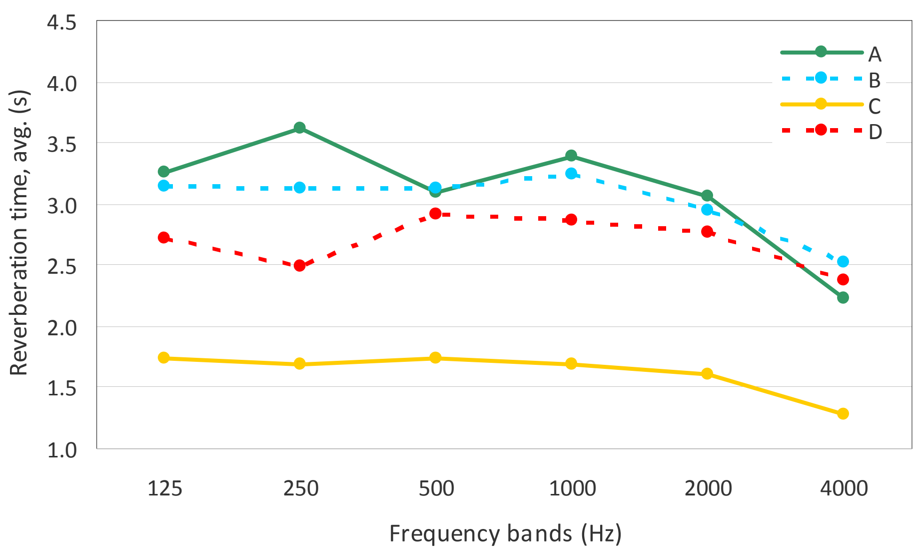


Figure 4: *Average RT variation in the food court, in shopping centers A, B, C and D*[1].

Table 3: RT values (avg. 500, 1k, 2k Hz) in the reference floor and food court, in malls *A*, *B*, *C* and *D*[1].

Shopping Center	RT (s) [avg. 500,1k,2k Hz]	
	Reference floor	Food court
A	3.0	3.2
B	2.9	3.1
C	1.7	1.7
D	2.8	2.8

Comparing the average *RT* values among each mall (Table 3) the longest value corresponds to mall *A*, heavily influenced by the high ceilings, the number of floors, the gallery type spatial configuration (with mezzanines), and the reduced sound absorption coefficients of coatings applied, such as ceramic and glass surfaces. Positively, shopping *C* has the minor (and best) *RT* values that correspond to the mall with fewer floors, smaller volume and consequently a less reverberant space. Its low-ceiling space configuration and the sound absorbent surroundings (decorative objects in the food court like lamps coated with canvas, drilled panels in the ceiling of the circulation areas on both floors, canvas in the entrances of restaurants) assist on the sound absorption of the space, reducing the reflections. Also helping is its spatial configuration like a long corridor in the reference floor, which makes it less spacious and therefore with shorter *RT* values.

Compared to the proposed ideal *RT* values (1.1 to 1.3 s) all malls in this sample are well above the upper limit, with the smallest and largest differences being in cases *C* and *A*, respectively 0.4 and 1.7 s.

3.3 Background Noise

To assess the background noise, measurements were done using a tripod supported B&K 2260 sound level meter and in two situations:

- Without occupation (in the food court and in the reference floor);
- With occupation (only in the food court).

In each mall, one to three different measurement positions were chosen for the sound level meter (Fig. 2) and, in each, with a five minute sampling.

At the non-occupation mode, the measurements were not carried out under "silence" since, in most cases, security and cleaning services were still present, causing some residual noise in addition to the intrinsic particular night noise in the commercial space (ventilation, lighting, etc.). In two shopping centers small sporadic work in shops and courts were under way preparing a future event in the food court. However there was particular care to only measure in the periods of greatest "silence", so that the captured noise matches the realistic intrinsic and permanent ambiance outside the opening hours of the shopping center.

Table 4 shows the L_{Aeq} overall average values of background noise for the measurements taken in the reference floors and food courts.

Table 4: Mean equivalent noise level (average log) of background noise (with and without occupation) in the reference floor and food court, in the four malls[1].

L_{Aeq} (dB)	Background Noise			
	Without occupation		With occupation	Variation Δ
	Reference floor	Food court	Food court	Food court
Mall				$\Delta = [L_{A\ occup.} - L_{A\ non\ occup.}]$
A	49.5	50.7	69.2	19
B	47.9	48.4	70.1	22
C	51.0	53.5	68.2	15
D	44.0	44.9	66.9	22

Without occupation, at the food courts, mall *C* shows the highest background noise L_{Aeq} possibly due to the particular sound of a refrigeration unit at an ice cream store. The presence of cleaning staff at the food court during measurements caused some noise by the cleaning equipment and dragging chairs and tables.

The food courts *C* and *D* correspond, respectively, to the worst and best cases regarding the noise measured without occupation, with the highest and lowest L_{Aeq}, 54 and 45 dB (a 9 dB variation). These situations are due to some small construction noise, to an ice cream machine, cleaning services, concurrently with the preparation of an event, adversely affecting background noise in *C*. In case *D*, despite construction work, measurements were fairly distant of this disturbance noise, adding the fact that there was no particular significantly intense noise when compared with other cases.

Without occupation, on the reference floor, shopping center *D* showed the lower background noise L_{Aeq} (44 dB). Also the food court *D* had the lowest L_{Aeq} (44.9 dB).

With occupation at food courts the highest L_{Aeq} was at mall *B*. On the evaluation day, food court *B* had a high occupational density: people talking, dragging chairs, etc. which effectively overrides other particular noise detected in the background noise. Together, all those actions generated a high equivalent sound level of occupation noise.

At food court *A* the high L_{Aeq} is due to the background music, the conversation between people, dragging chairs, the noise of the trays and their dishes, and the particular noise in play area.

Food court *B* was the most problematic case, in contrast to *D*, through a L_{Aeq} of 70 and 67 dB. The L_{Aeq} variation has a narrow range of 3 dB, since in all malls on the measurements' day the occupation density was high, experiencing some noises in common, such as conversation and dragging chairs. Even though it was measured at lunchtime, so more people, mall *D* was the "best", since it is a very large space, where people do not tend to concentrate so much and the sound absorbent ceiling assists in the reduction of ambient noise (as opposed to case *B* as it does not present this material). The presence of background music and sound of water help to mask the most intense noise of the occupation, because these are pleasant and relaxing sound sources, helping users to make the effort to hear them instead to produce more noise.

All the studied cases (in occupation mode) exceeded the proposed ideal value of 55 dB(A) by 12 to 15 dB(A).

The L_{Aeq} without occupation was strongly influenced in some cases by non-current or intrinsic noise, as small construction works and the preparation of future events. Removing these “casual” noises, is possible to make a close estimate of the increase of the L_{Aeq} noise by the occupancy in relation to the non occupied noise, using as reference the L_{Aeq} for mall *D* (best case for noise measured without occupation). Considering as reference its 45 dB as the L_{Aeq} (unoccupied) for all food courts studied, the variation between the noise detected in the two modes can be better estimated (Table 5). The shopping centers in operation do predictably increase the background noise from 22 to 25 dB(A) over the background noise without occupation. Figure 5 shows a similar analysis but with the sound pressure levels in one particular point of the worst case (*B*) where it is shown that the occupation increases background noise for about 22 dB in the 500-8k Hz range where al the important speech sounds are.

Table 5: The global L_{Aeq} mean values for food courts *A*, *B*, *C* and *D*, with and without occupation (* reference value = lowest value obtained at all shopping centers)[1].

Food Court	**L_{Aeq} (dB) Mean values**		
	With occupation	**Without occupation**	**$\Delta = [L_{occup.} - L_{no.occup.}]$**
A	69	45 *	24
B	70		25
C	68		23
D	67		22

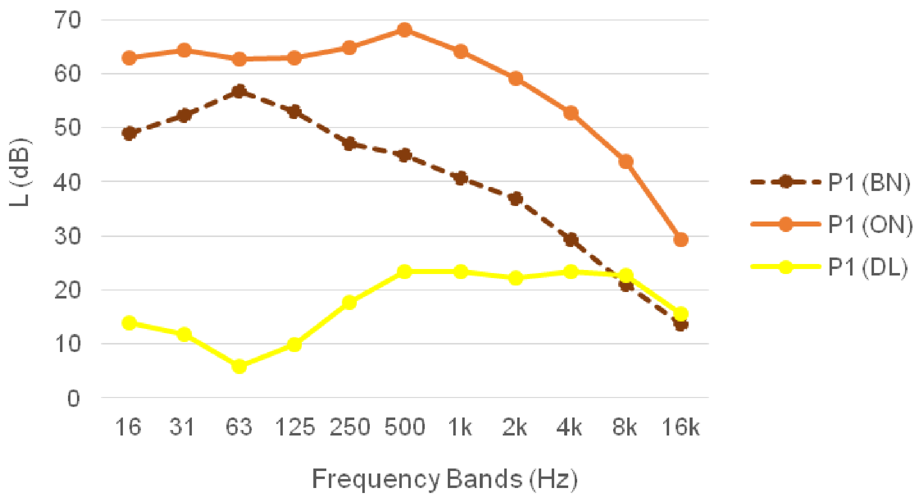


Figure 5: *Sound pressure levels of background noise, without occupation (BN) and with occupation (ON) and their variation (DL = L ON - L BN) at the measuring point P1 in the food court B (the worst case studied with occupation).*

3.4 Rapid Speech Transmission Index (RASTI)

The speech intelligibility in the shopping centers was indirectly evaluated through *RASTI* (Rapid Speech Transmission Index) using a transmitter (B&K 4225) supported on a tripod and a receiver (B&K 4419) handled by the surveyor. The sound source was positioned at a height of about 1.6 m above the floor, while the microphone simulated the ears position of a receptor in six positions (Figure 6). The results were obtained through the arithmetic mean of the measurements. The *RASTI* measurements were done after the closure of the shopping centers in the food courts (non-occupation mode).

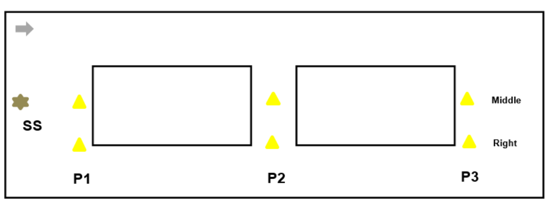


Figure 6*: General outline of the spatial configuration of the studied area for RASTI, sound source location (SS) and measuring points (P1 to P3).*

Table 6: RASTI values (average) in food courts of the shopping centers[1]:

Food Court	RASTI average	Speech intelligibility classification
A	0.42	*Poor*
B	0.41	*Poor*
C	0.45	*Fair*
D	0.51	*Fair*
Δ = [max. – min.]	0.10	-

The Table 6 compares the average *RASTI* values and the related subjective speech intelligibility classification in the food courts of the studied shopping centers. The shopping center *B*, one of the more reverberant spaces, characterized the worst evaluation of *RASTI* with 0.41.

The *RASTI* was measured "without occupation" so, if it were estimated "with occupation" it probably had worse results, the speech intelligibility would probably be *bad*. The *RASTI* value in *B* suggests a weak speech intelligibility due also to the noise of the refrigeration machines in the food courts, particularly due to a very noise refrigeration machine in an ice cream shop. The shopping center *D* exhibited the best evaluation of *RASTI*, with an average value of 0.51, associated with the lowest L_{Aeq} background noise stated and also with less noise produced by restaurants' machines, as opposed to the other spaces. The variation of this parameter was small but allows highlighting the worst and best perception of the speech in cases *B* and *D*, respectively classified as *poor* and *fair* speech intelligibility. These differences have the support of the existence of absorbent perforated panels in the measurement zone of the case *D*; and the best *RASTI* values are in the food courts with the shorter *RTs*; and as noted, *D* was the shopping center with less noise occupation. According to the proposed ideal value *RASTI* (≥ 0.45) cases *A* and *B* do not reach the appropriate minimum, in contrast with *C* and *D*.

4. CONCLUSIONS

The measured acoustic parameters are quantitatively and qualitatively summarized in Table 7 for their global values and the corresponding subjective assessment in the studied food courts.

Regarding *RT* the food court *A* exhibited the longest average *RT* (3.2 s), corresponding to the worst case studied (the reference floor also had the longest *RT*). The most excessive *RT* values were measured in the frequency bands of 500 to 2k Hz, those deeply related with speech, which can trigger difficulties on speech intelligibility. In contrast, food court *C* stood out as the best sample, with the lowest *RT* value (1.7 s, also measured on the reference floor). The variation of the overall *RT* values among the four food courts was significant (1.5 s) showing that differences in the design/materials can play a significant role. However, in all cases the *RT* were above the maximum limit of the proposed ideal *RT* values with smaller and larger difference in cases *C* and *A* (respectively 0.4 and 1.7 s), thus revealing a general tendency for the reflected sounds to overlap the direct sounds in this type of environment.

Table 7: Qualitative and quantitative analysis of the global RT (s), L_{Aeq} (dB) and ΔL_{Aeq} (dB) (difference related to 45 dB(A) reference of the lower background noise measured without occupation), with respective variation and ideal values, in the food courts (*A*, *B*, *C* and *D*)[1] (W - Worst, B - Best, of the sample).

Shopping centers (Food Courts)	RASTI avg.	RT (s) [avg. 500, 1k, 2k Hz]	Background noise *With occupation*	
			L_{Aeq} (dB)	ΔL_{Aeq} (dB) [$L_{occup.} - L_{no.occup.ref.}$]
A	0.42	3.2 W	69	24
B	0.41 W	3.1	70 W	25
C	0.45	1.7 B	68	23
D	0.51 B	2.8	67 B	22
Δ=[max.-min.]	0.10	1.5	3	3
Ideal values	≥ 0.45	1.1 to 1.3	≤ 55	-

About background noise, food court *B* was the worst case (L_{Aeq} of 70 dB) and *D* was the best case with occupation (L_{Aeq} of 67 dB). The L_{Aeq} variation presented a relatively small range of 3 dB in occupation mode, explained by the similar day and time of measurements, and the high occupational density in all shopping centers, indicating a fairly common acoustic environment for all malls. In the occupation mode all cases exceeded the proposed ideal BN maximum value of 55 dB(A), from 12 to 15 dB(A), almost an alarming reality. The level of occupancy noise showed a rather excessive value for acoustic comfort and well-being in shopping centers. Not only by the feeling of discomfort but also for "incompatibility" relatively to speech intelligibility. When noise is high makes an acoustically unfavorable space, especially if it intensifies in frequency with the highest hearing sensitivity, between 1 and 4 kHz.

The *RASTI* revealed reasonable values in this study, but in a no occupation mode (credible measurements with occupation are harder to perform). If without occupation the speech intelligibility classified as *fair-poor*, it is expected that an evaluation with occupation, during mall normal operation hours, the *RASTI* would be lower. So, in occupation mode, a *poor-bad RASTI* could be reasonably expected in hours of higher occupancy density, especially in the more critical spaces where higher *RT* values and L_{Aeq} levels are present (malls *A* and *B*).

The confined environment of each space has a decisive role in the definition and acoustic quality of it. The surrounding characteristics, from the dimensions to the type of coating materials, together with the intrinsic local objects, explained the conclusions drawn. Of all the characteristics, the main negatives points for acoustics are: number of floors, height and volume; gallery configuration linking the different spaces of the malls assisting in the spread of noise; reduced area of food courts concentrating people and centralizing activities and access; surface coatings with reflective materials (such as ceramic, marble or ceramic tiles) and glass surfaces; little or no application of absorbents materials and systems; noisy machines and equipments, little or nothing acoustically treated; carts without silent bearings and chairs and tables with worn rubber or without them producing noise when dragged. In contrast, the positive characteristics observed in some of the cases studied are: height and volume reduced; spatial configuration like long corridors, with little interaction between the spaces; large food courts so as not to agglomerate people, and consequently the noise. Other favorable characteristics detected that, in the absence, can also be taken as intervention proposals, include: acoustic treatment of the particular noise of machines and equipments through quieter cooling systems/ventilation/others; presence of rubber in the legs of tables and chairs; silent bearings in the carts; and especially lesser application of reflective materials over sound absorptive, for example, perforated panels and/or baffles in the ceiling, porous and fibrous materials in the decorative objects (tissues, cushioned) and on the walls (wood fiberboard agglomerate, etc.), as well as more areas with sofas and carpets. Note that these and many other examples can be considered for proper acoustic corrections.

In general, a minimal careful acoustical design can decrease the average *RT* up to 1.5 s, increase the average *RASTI* up to 0.10 and decrease the occupation background noise in 3 dB(A).

Therefore, succinctly: to reduce the reverberation of space through the type and shape of the surfaces and volume; increase sound absorption and reduce the effects of noise sources, in order to reduce ambient noise. Sound absorption of the environment is the basis of the best results of the acoustics of shopping centers. All these factors contribute for better speech intelligibility, better quality and comfort of space, consenting users to spend more time in shopping centers.

Of all the construction requirements which carry a particular project, perhaps the most ignored is Acoustics because the aesthetics almost always tends to overlap. However, these are old approaches that can no long happen. In the long run an acoustically bad space will have fewer customers than others better designed.

REFERENCES

1 Cláudia F. R. T. Pereira, *Acoustic characterization of large shopping malls – shopping centers of Oporto*. [in Portuguese], M.Sc. thesis Civil Eng., Fac. Eng. U. Porto, 2015.