



Sound absorption of church pews

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This paper presents the results regarding sound absorption measurements in a reverberation room by EN ISO 354, of samples of three different types of commonly used church pews, in several situations: with and without occupation; with and without seat cushions. Results are analyzed by area, by individual pew and by an enlarged "acoustic" area.

1 INTRODUCTION

The goal of this study was to find the sound absorption of wooden benches, the typical church pews, using three types as case study. It was also an objective to check how the pew sound absorption changes, with the use of seat cushions, and by their occupancy. Therefore also measurements in all those situations were performed.

2 MEASUREMENTS

The measurements to get the sound absorption were done in the main reverberant chamber (about 200 m³) of the Laboratory of Acoustics in the Faculty of Engineering of the University of Porto (FEUP), Portugal, using the standard EN ISO 354¹. Five positions of the sound source for four positions of the microphone (and three measurements for each configuration sound source/microphone) were used.

Three different types of pews (here named *F*, *N*, and *A*) were used with three elements of each type (Fig. 1, 2 and 3). They were tested unoccupied and with the occupation of persons or seat cushions. Pew type *F* (as in *FEUP*) were provided by FEUP (fig. 1) and are old specimens once in use in the former building of this college at Rua dos Bragas (Bragas' street in downtown Porto). The pews named type *A* (as in *Antique* or *old*) and *N* (as in *New*) were provided by the Parish of Santo Ovídio (Vila Nova de Gaia, Portugal), and are samples of the ones that exist inside its old and new churches (figs. 2 and 3).

The measurements with the occupied pews were done using, as figurants, students from the FEUP M.Sc. level course of Building and Environmental Acoustics (Fig. 5) with five persons per

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pew (for pews F) and six persons per pew (for pew types A and N). Figures 4 and 6 as well as table 1, show the basic drawings and the dimensions of the pews and seat cushions (Fig. 6).

Table 2 displays the dimensions of the tested areas of pews and the corresponding areas used in the calculation of the sound absorption. S stands for the real surface area effectively occupied by the three pews (fig. 7) and S_+ (increased surface area or “acoustical area”) considers also the additional areas of strips 0.5 m (20 in.) wide around the block of the real seating area (fig. 8) as suggested in ².

2 RESULTS

2.1 Types of Analyses

For the calculation of the sound absorption three different analyses were done, named Types I , II and III as follows:

- I (A/pew) - Individual sound absorption; Sound absorption (m^2) for each pew because the samples are discrete elements; it allows, for instance, to check how many pews would be necessary to reach certain amount of total sound absorption but only if the pews were used with a reasonable separation among them.
- II (At/S or A/m^2) - Total sound absorption (At) divided by the real surface area (S) occupied by the pews because it is a group of objects that are usually used in a cluster with small spaces among them within a church.
- III (At/S_+ or $A/m^2_{increased}$) - Total sound absorption (At) divided by the increased area (S_+) that is, the area S occupied by each set of three pews plus additional areas of strips 0.5 m (20 in.) wide around the S block of the real seating area. According to Beranek² this roughly assumes that the acoustical area of the congregation is 0.5 m larger on all sides than the real area (S) over which it sits. It makes for a fictitious increase of the absorption area when there is a close use of the pews.

2.2 Sound Absorption by Pew (Type I)

Figures 9 to 11 show the results for the three types of pews using analysis *type I* sound absorption by pew (A/pew) (different vertical axis' scales were used for better visual adjustment to each situation).

The sound absorption of the unoccupied pews (fig. 9) is generally low (about 0.25 m^2/pew) but type N pews are those that display a larger absorption in the majority of frequency bands. This happens because they are the heavier from all three pew types and the ones that have the lowest area of openings, that is, a higher area able to absorb. It is in the low frequency bands that pew type A shows the smaller absorption comparing with the other pews (it is the one that has the smaller area of material).

In the situation of occupied pew or with seat cushions (figs. 10 and 11), the sound absorption in the low frequency bands is very similar for all three types of pews. Pew type F presents the smallest sound absorption for medium and high frequency bands in the situation of occupied pew and with seat cushions, because the available area for absorption is smaller. Pews type F are the smallest of the tested (Tables 1 and 2), allowing for less persons and seat cushions.

Figure 12 displays the average values found for the three types of pews jointly, for each situation (occupied, with seat cushions and unoccupied pews) that is, for each line, the average of figures 9, 10 and 11 data). The occupied pews average absorption data show, for the higher

frequency bands, almost the triple sound absorption values, when compared with the situation of pews with seat cushions.

Figure 13 presents the sound absorption variations for each pew ($\Delta A/pew$) for all situations:

- Effect of pew occupation: variation of the sound absorption of the occupied pew regarding the unoccupied pew ($\Delta A,o = A/pew_occupied - A/pew_unoccupied$);
- Effect of the seat cushions: variation of the sound absorption of the pew with seat cushions from the unoccupied pew ($\Delta A,sc = A/pew_seat\ cushion - A/pew_unoccupied$);
- Effect of occupation vs. seat cushions: variation of the occupied pew sound absorption relatively to the pew with seat cushions ($\Delta A,o-sc = A/pew_occupied - A/pew_seat\ cushions$).

The goal is to check the increase in sound absorption (ΔA) by pew in each of the three situations. That increase is larger in the situation of occupied pews ($\Delta A,o$). Pew type *A* is the lightest and with more openings, so, when occupied or with seat cushions the variation in sound absorption is larger. For pew type *F*, notwithstanding not being the one with the smallest mass, is the one that shows the least influence in the sound absorption for the situation of occupied pew and with seat cushions because in the measurements with persons and with seat cushions, less persons were needed because of their smaller length (Table 1).

2.3 Sound Absorption by Area (Type II)

Figures 14 to 16 display the results of total sound absorption by sample area S (A_t/S).

The surface area (S) occupied by the three pews type *F* sample is the smallest of all types under study (Table 2). For this reason the total sound absorption, also smaller than for the other pew types, is divided by a smaller area than the others. This difference in the analyses is enough to explain that pew type *F* is the one that absorbs the most (figs. 14 to 16). The same explanation is valid for the differences in the variations (ΔA) because in this situation it is not the individual element (each pew) that is accounted for but the entire area S occupied by the pews.

Figure 17 presents the average values found for the comprehensive data of all three types of pews, for the three situations analyzed (each line represents the average of the results of the three pew types as one, that is, the average of each of the figures 14, 15 and 16 data).

For the occupied pews (fig. 17 upper line) the average sound absorption by m^2 in the entire frequency range shows three different paths: Until 250 Hz the sound absorption has values very close to 0.4. From 250 Hz to about 630 Hz the sound absorption values by m^2 increase to about 1.4, stabilizing in the third track (above 800 Hz) in values from about 1.6.

For the pews with seat cushions (fig. 17 middle line) there is a first branch growing up to the 500 Hz reaching a relative absorption value of 0.8, decreasing, in a second track, up to a values around 0.6, from 1600 Hz, stabilizing in that value up to the 5000 Hz.

For the unoccupied pews (fig. 17 bottom line), the values stay very close from the 0.1 for the entire range of frequencies.

Figure 18 shows the variations of sound absorption (ΔA) in the three following situations:

- Effect of the occupancy: variation of the relative sound absorption of the occupied pew comparatively to the unoccupied pew ($\Delta A/S,o = A/S_occupied - A/S_unoccupied$);
- Effect of the seat cushions: variation of the pew relative sound absorption with seat cushions comparatively to the unoccupied pew ($\Delta A/S,sc = A/S_seat\ cushions - A/S_unoccupied$);
- Effect of the occupancy *versus* seat cushions: variation of the occupied pew relative sound absorption comparatively to the pew with seat cushions ($\Delta A/S,o-sc = A/S_occupied - A/S_seat\ cushions$).

These variations are obtained by the same method used with the A/pew analysis but now, the entire area that the sample occupies (S) is accounted for and not the number of pews that each sample has. This implies a change in the sound absorption range of values and also in the way that each pew type is arranged regarding their sound absorption relative values. In this way it is more clear the importance that pew mass and pew opening areas have.

2.4 Sound Absorption by Increased Area (Type III)

Figures 19 to 21 present the results of the total sound absorption by increased area (At/S_+) among pew types (different vertical axis' scales are used to better allow the reading of each graph). Despite having a different range of measured values in this approach, in relative terms the conclusions are the same as those stated for the previous type II approach (At/S).

Figure 22 presents the grouped average values for the three pew types, for each situation (unoccupied, occupied and with seat cushions). Each line represents the average of the results of the three pew types as one, that is, the average of each of the figures 19, 20 and 21 data).

For the occupied pews (fig. 22 upper line) the average sound absorption by increased m^2 in the frequency range has, as in the previous approach, three different branches: Until the 250 Hz, relative sound absorption values have values close to 0.2. From the 250 Hz to the 630 Hz frequency band, the A/S_+ values raise up to about 0.7, stabilizing in the third branch (from about 800 Hz) in values around 0.8.

For the pews with seat cushions (fig. 22 middle line), a first branch is shown increasing up to 500 Hz, reaching values of 0.4; decreasing, in a second branch, up to a value close to 0.3; from 1600 Hz, keeping in that same range of values until the 5000 Hz.

For the situation of unoccupied pews (fig. 22 bottom line), the absorption relative values are close to 0.06 in the entire frequency range.

Figure 23 presents the variations of relative sound absorption ($\Delta A/S_+$) in the three following situations:

- Effect of the occupancy: variation of the relative sound absorption of the occupied pew comparatively to the unoccupied pew ($\Delta A/S_{+,o} = A/S_{+,occupied} - A/S_{+,unoccupied}$);
- Effect of the seat cushions: variation of the pew relative sound absorption with seat cushions comparatively to the unoccupied pew ($\Delta A/S_{+,sc} = A/S_{+,seat\ cushions} - A/S_{+,unoccupied}$);
- Effect of the occupancy *versus* seat cushions: variation of the occupied pew relative sound absorption comparatively to the pew with seat cushions ($\Delta A/S_{+,o-sc} = A/S_{+,occupied} - A/S_{+,seat\ cushions}$).

These variations ($\Delta A/S_+$) are calculated by subtracting the sound absorption for the unoccupied pews, from the sound absorption for the occupied pews or with seat cushions, and by subtracting the sound absorption for the pews with seat cushions from the sound absorption of the occupied pews. In this approach the increased area (S_+) is used. This generates a change in the range of values for the relative sound absorption comparatively to the previous approach.

3 NEW SOUND ABSORPTION PARAMETER FOR PEWS

It is useful to have a single number to characterize the pews' sound absorption to facilitate the communication among acoustical consultants, manufacturers or companies. For this reason a new parameter is proposed $NRC(pew)$ derived from the *Noise Reduction Coefficient*, as the arithmetic average of the sound absorption A in the octave frequency bands from 250 Hz to the 2000 Hz (Eq. 1). Table 3 displays the values for this new parameter for the three pews in the

three analysed situations (pew unoccupied, occupied and with seat cushions). The $NRC(p)$ is calculated using the approach of the increased area (S_+), that is, A/S_+ .

$$NRC(p) = (A_{250} + A_{500} + A_{1k} + A_{2k}) / 4 \quad (1)$$

4 CONCLUSIONS

Differences were found in the range and in the relative arrangement of sound absorption values, for the three types of pews. While in the approach A/pew , for the unoccupied pews, it is pew type N that shows the largest sound absorption, in the two approaches in which the sample area is accounted for, the largest absorber is type F . This is due mainly to the differences that exist in the areas occupied by each sample.

These differences are less significant in the measurements with seat cushions and with persons. The largest difference was found for pew type F because it is the smallest pew and the number of seat cushions and persons on it was lower than in the other types (five and not six persons/pew). The values for pews type N and A are very close in all approaches and the small differences found can be justified by the area or number of pews in each sample, like in the situation of unoccupied pews.

By figures 13, 18 and 23, it is shown that the gain in absorption (ΔA) achieved by the use of seat cushions is about one third than that by the person occupation of the pews. This reveals that if the pews have seat cushions or are upholstered, the sound absorption variation compared with pews non completely occupied is smaller, achieving this way a smaller variation in the global acoustic characteristics of the church (in the RT values).

Table 4 presents the average absorption values for the three types of pews (unoccupied, occupied and with seat cushions) for the three approaches studied, that are proposed to be used as reference values for the sound absorption of church pews. The approach of sound absorption by individual pew (A/pew) may be useful in the calculation of the number of necessary pews to reach a certain amount of sound absorption but only if the pews are used with a reasonable large spacing among them. The approach of sound absorption by $m^2_{increased}$ (A/S_+) is the most reliable method because it accounts for the acoustical behaviour of the group of pews in a somewhat confined arrangement.

5 ACKNOWLEDGEMENTS

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6 REFERENCES

1. EN ISO 354, *Acoustics, Measurement of sound absorption in a reverberation room*, CEN (2003).
2. Leo Beranek, *Concert and opera halls: how they sound*. Acoust. Soc. of Am., USA, (1996).
3. Joana S. O. Pino, *Estudo Acústico de Bancos de Igreja*, Master of Science Thesis, Civil Engineering, FEUP - Faculty of Engineering University of Porto, Portugal, (2011).

Table 1 – Dimensions of pews and seat cushions used in the measurements (see fig. 4).

Sample	$h1$ (m)	$h2$ (m)	c (m)	L (m)	La (m)	Lg (m)	e (m)	Seating area (m ²)
Pew <i>F</i>	0.945	0.460	2.02	0.380	0.38	-	-	0.768
Pew <i>A</i>	0.850	0.440	2.80	0.451	0.39	0.277	-	1.092
Pew <i>N</i>	0.970	0.455	2.80	0.435	0.44	-	-	1.232
Seat cushion	-	-	0.49	0.550	0.45	-	0.045	0.245

Table 2 – Dimensions of the areas occupied by the different types of pews in the measurements in the reverberant chamber ($S_+ = S + 0.5$ m wide strip around S).

Sample area	Pew <i>F</i>	Pew <i>A</i>	Pew <i>N</i>
Normal S (m ²)	4.63 (= 2.02 × 2.29)	7.56 (= 2.80 × 2.70)	6.50 (= 2.80 × 2.33)
Increased S_+ (m ²)	9.94 (= 3.02 × 3.29)	14.06 (= 3.80 × 3.70)	12.65 (= 3.80 × 3.33)

Table 3 – Values of sound absorption by $m^2_{increased}$ (A/S_+) and $NRC(p)$ for each type of pew unoccupied, occupied and with seat cushions (and its mean value).

$A/S_+ (= A/m^2_{increased})$	Frequency band (Hz)							$NRC(p)$
	125	250	500	1000	2000	4000		
Pew unoccupied								
Pew <i>F</i>	0.03	0.06	0.06	0.06	0.05	0.08	0.06	
Pew <i>A</i>	0.01	0.01	0.03	0.04	0.05	0.06	0.03	
Pew <i>N</i>	0.04	0.05	0.07	0.09	0.09	0.07	0.07	
Average of all three pew types	0.03	0.04	0.05	0.06	0.06	0.07	0.05	
Pew occupied								
Pew <i>F</i>	0.20	0.36	0.68	0.81	0.85	0.82	0.67	
Pew <i>A</i>	0.15	0.26	0.59	0.73	0.78	0.78	0.59	
Pew <i>N</i>	0.17	0.32	0.63	0.81	0.86	0.83	0.65	
Average of all three pew types	0.17	0.31	0.63	0.78	0.83	0.81	0.64	
Pew with seat cushions								
Pew <i>F</i>	0.12	0.30	0.41	0.34	0.29	0.31	0.34	
Pew <i>A</i>	0.09	0.23	0.34	0.32	0.27	0.28	0.29	
Pew <i>N</i>	0.10	0.26	0.41	0.38	0.32	0.30	0.34	
Average of all three pew types	0.10	0.26	0.39	0.35	0.29	0.30	0.32	

Table 4 – Proposed average sound absorption values to be used as reference for church pews (= arithmetic average of the measured values for the three types of pews in one third octave band).

Situation	Pew	Freq. (Hz)	125	250	500	1000	2000	4000
A/pew (m ²)	Unoccupied		0.12	0.16	0.21	0.26	0.26	0.28
	Occupied (with persons)		0.69	1.25	2.55	3.17	3.37	3.29
	With seat cushions (without persons)		0.42	1.06	1.56	1.40	1.19	1.19
A/S (A/m ²)	Unoccupied		0.06	0.09	0.10	0.13	0.12	0.14
	Occupied (with persons)		0.35	0.63	1.26	1.55	1.65	1.61
	With seat cushions (without persons)		0.21	0.53	0.77	0.69	0.58	0.59
A/S_+ (A/m ² _{increased})	Unoccupied		0.03	0.04	0.05	0.06	0.06	0.07
	Occupied (with persons)		0.17	0.31	0.63	0.78	0.83	0.81
	With seat cushions (without persons)		0.10	0.26	0.39	0.34	0.29	0.29



Fig. 1 (left), 2 (center) and 3 (right) – Pews type F (left), type A (center) and type N (right) in the reverberant chamber.³

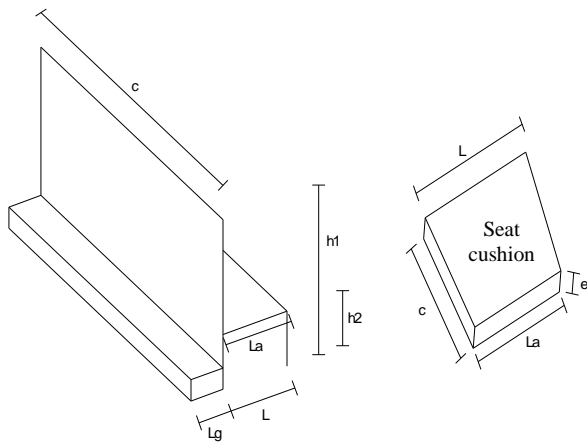


Fig. 4 (left), 5 (right above) and 6 (right below) - Pew and seat cushion schemes to support Table 1 (left), example of pews with occupation (right above) and seat cushions used (right).

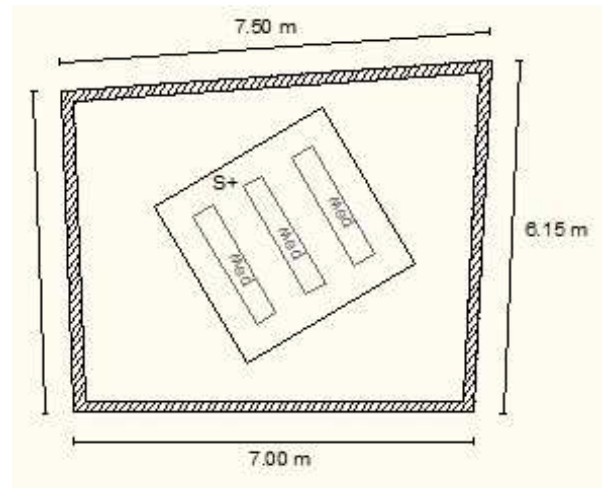
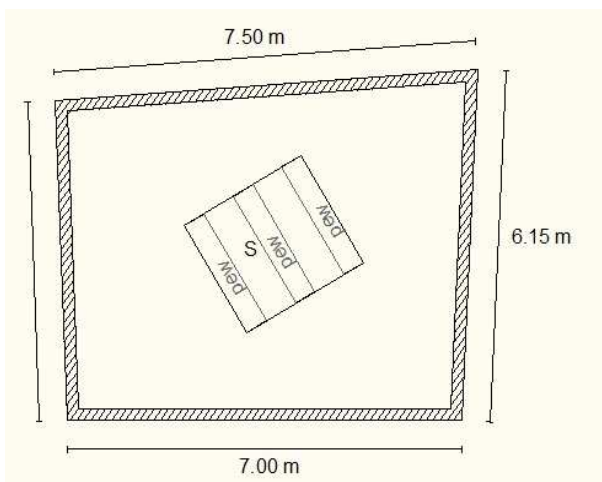


Fig. 7 (left) and 8 (right) – Plans of the reverberant chamber with: S , surface area occupied by each set of three pews (left); S_+ , increased area, occupied by each set of three pews plus additional areas of strips 0.5 m (20 in.) wide around the S block of the real seating area, as in ² (right).

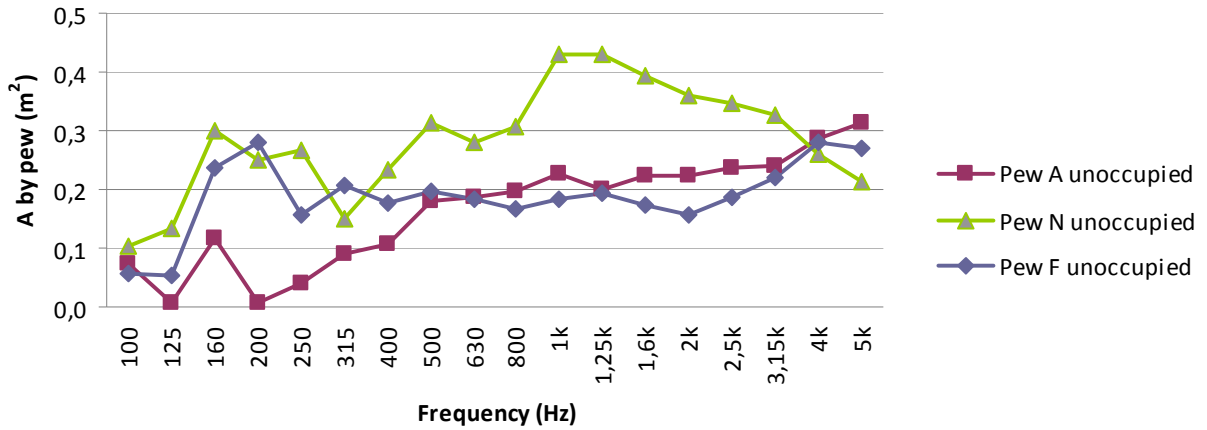


Fig. 9 – Sound absorption (m^2) for one unoccupied pew (A, N and F).

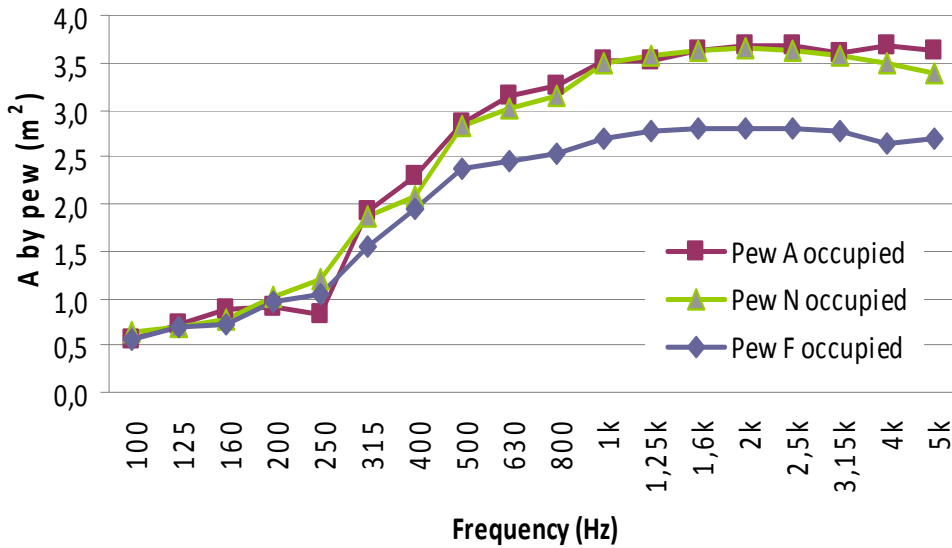


Fig. 10 – Sound absorption (m^2) for one occupied pew.

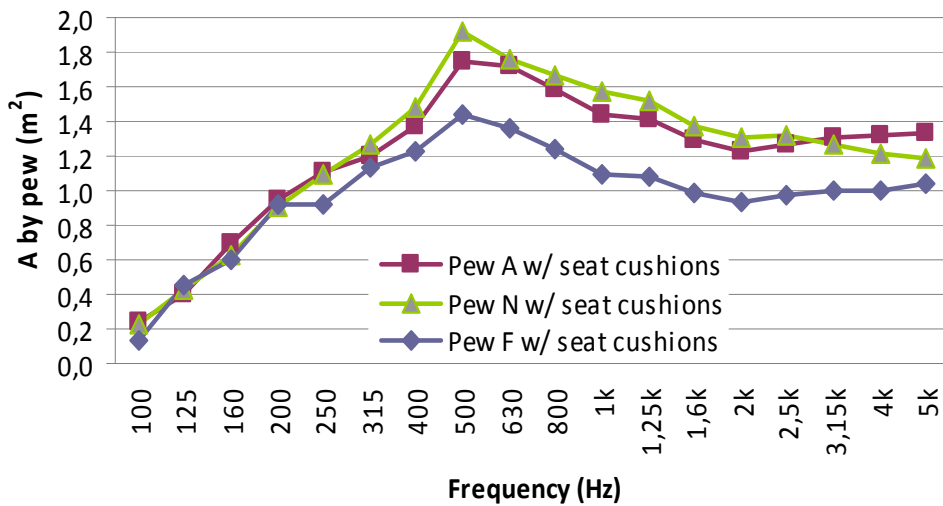


Fig. 11– Sound absorption (m^2) for one pew with seat cushions.

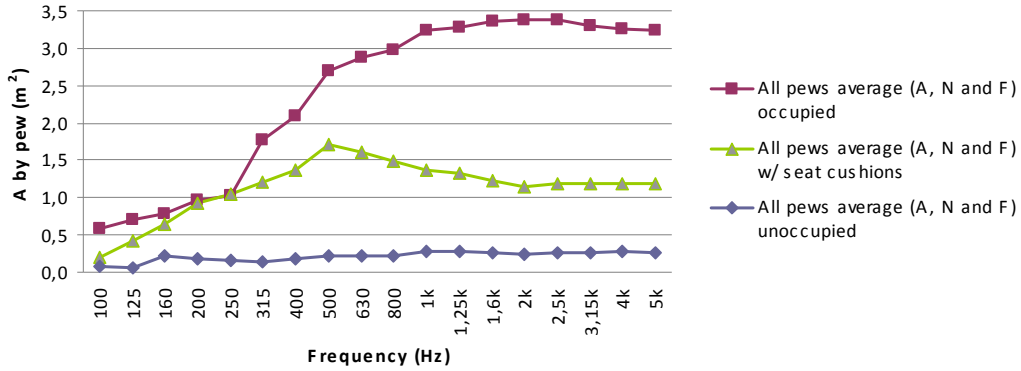


Fig. 12 – Average sound absorption (m^2) for one pew; each line represents the results' average of the three types of pews jointly (A, N and F), that is, the average of figures 9, 10 and 11 data.

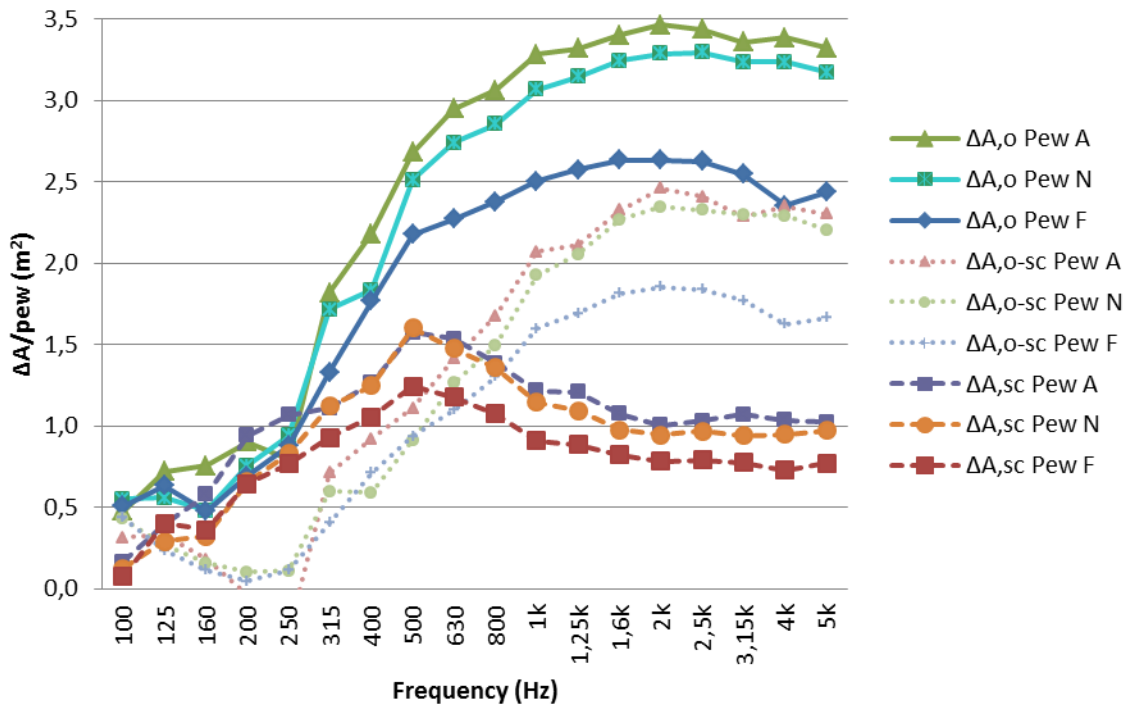


Fig. 13 – Variation of sound absorption (ΔA) by pew, occupied ($\Delta A_{,o}$) or with seat cushions ($\Delta A_{,sc}$) relatively to the unoccupied pew and occupied pew relative to a pew with seat cushions ($\Delta A_{,o-sc}$).

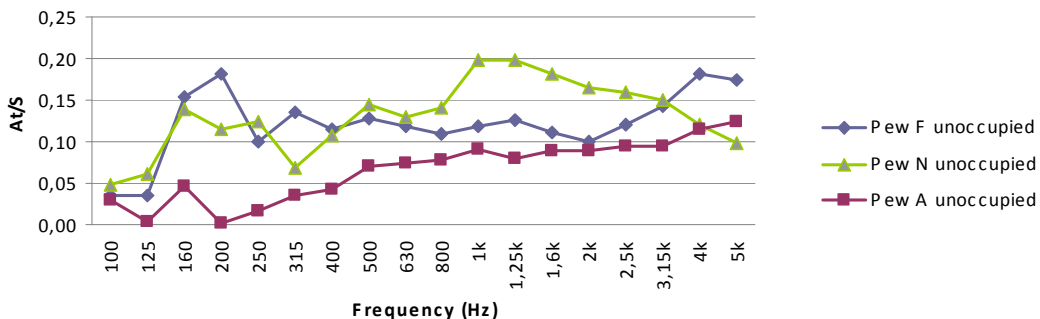


Fig. 14 – Sound absorption by sample area S , for unoccupied pews (F, N and A)

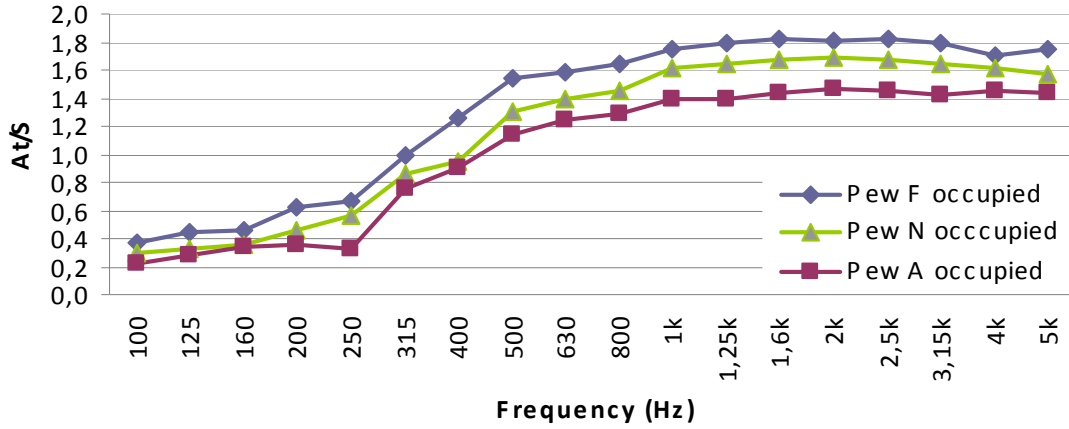


Fig. 15 - Sound absorption by sample area S , for occupied pews.

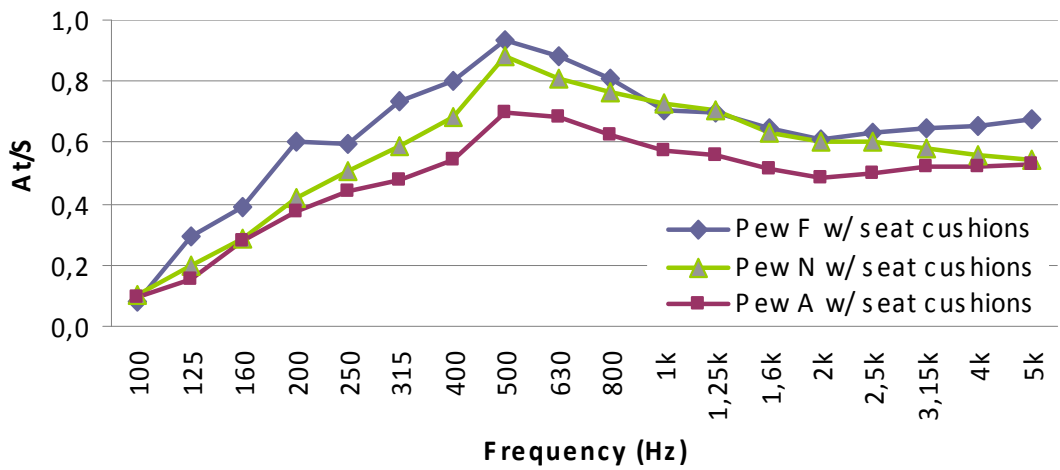


Fig. 16 - Sound absorption by sample area S , for pews with seat cushions.

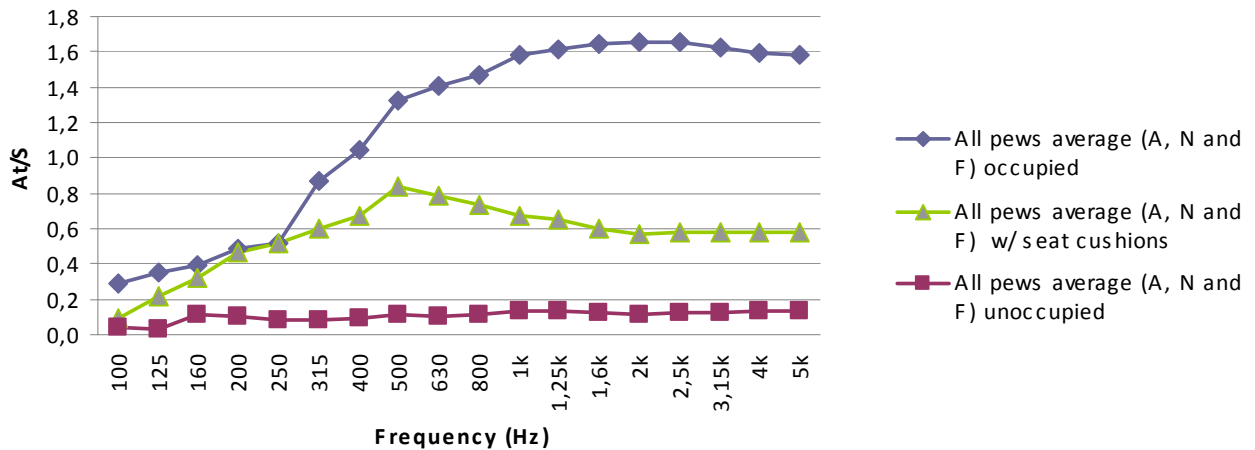


Fig. 17 – Average sound absorption of the three types of pews (A, N and F) as one by surface area (At/S) that is, each line is the average of figures 14, 15 and 16 data.

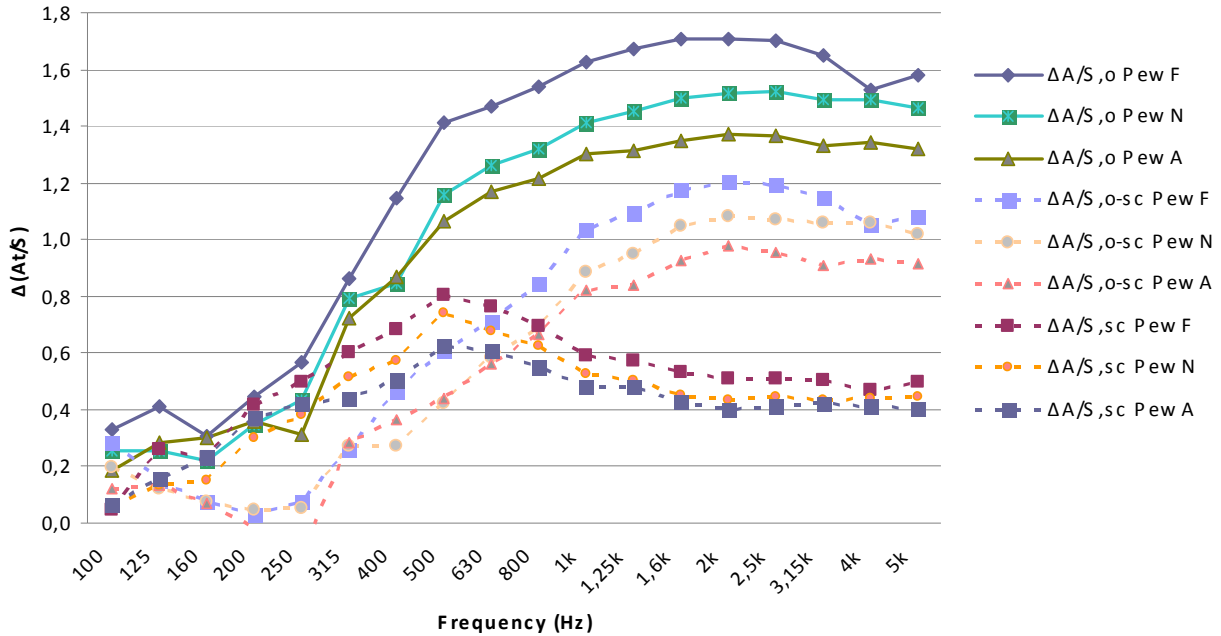


Fig. 18 - Variation of sound absorption by m^2 [$\Delta(A_T/S)$] of occupied pews ($\Delta A/m^2,o$) or with seat cushions ($\Delta A/m^2,sc$) relatively to unoccupied pews and occupied relative to pews with seat cushions ($\Delta A/m^2,o-sc$).

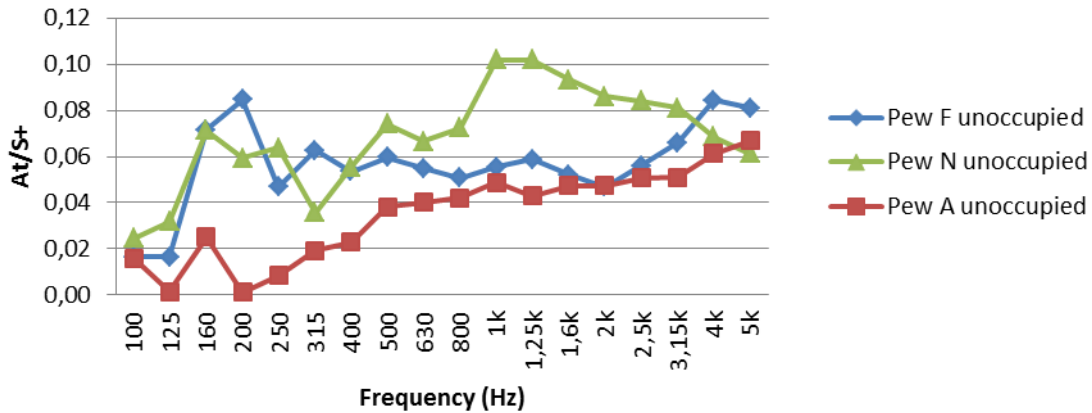


Fig. 19 – Sound absorption by increased area (S_+) of unoccupied pews (F, N and A)

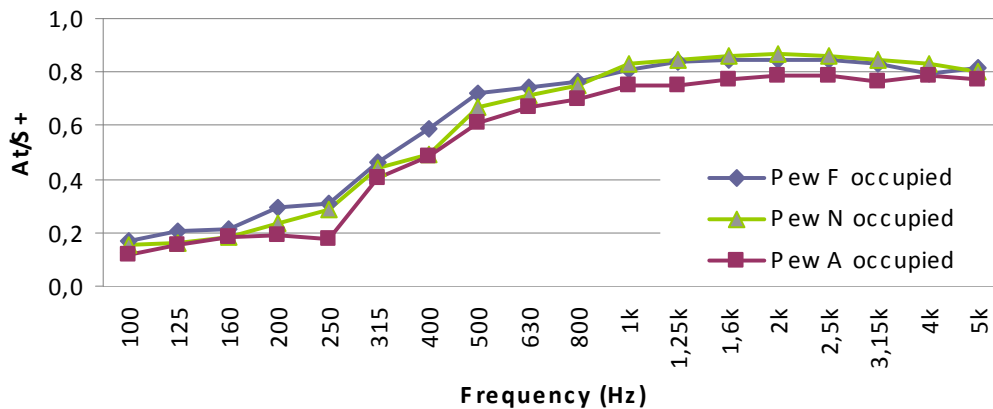


Fig. 20 – Sound absorption by increased area (S_+) of occupied pews (F, N and A).

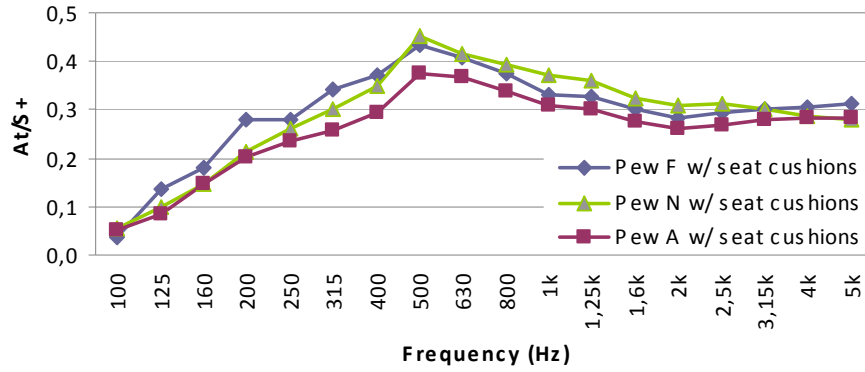


Fig. 21 – Sound absorption by increased area (S_+) of pews with seat cushions (F, N and A).

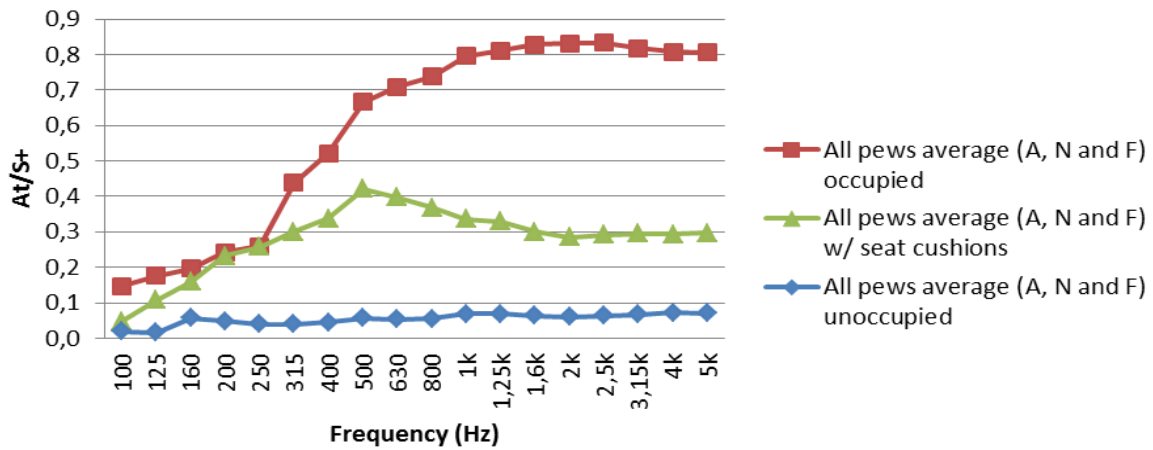


Fig. 22 – Average of all three types of pews (F, N and A) sound absorption by increased area (S_+) that is, each line is the average of figures 19, 20 and 21 data.

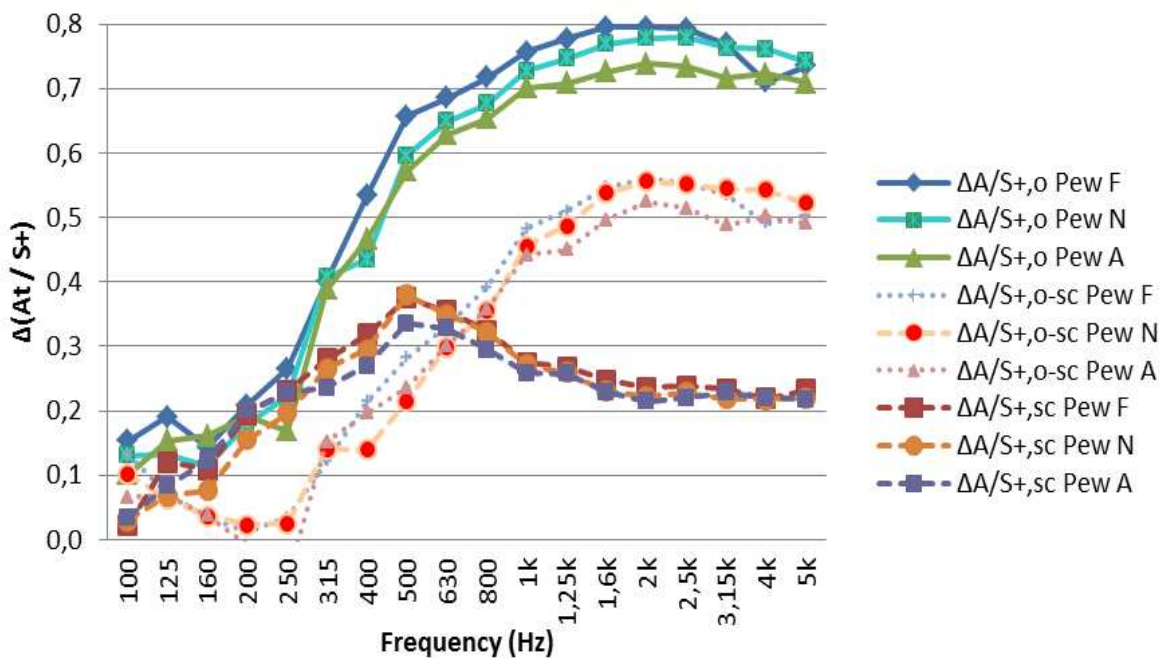


Fig. 23 – Variation of sound absorption by m^2 increased (S_+) of the occupied pews ($\Delta A/S_{+,o}$) or with seat cushions ($\Delta A/S_{+,sc}$) relatively to the unoccupied pews and occupied relatively to the pews with seat cushions ($\Delta A/S_{+,o-sc}$).