Influence of the type of fastening of multi-layered closing panels on the estimate of the sound transmission loss

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Abstract

Industrialized closing systems appear as rational solutions in steel-structured construction. These closing systems, consisting of multi-layered panels, have been applied in projects where it is intended to obtain a high sound transmission loss without raising the cost and without using a lot of mass. However, acoustic isolation depends on several factors, including the type of connection between the panels, requiring a preliminary study of the acoustic performance of the closing system to prevent future interventions. This paper uses a simplified graphical method to evaluate the influence of the type of connection (line-line, line-punctual or punctual-punctual) of industrialized closing panels on the estimation of the sound transmission loss that occurs across the wall constituted by these panels. The panels are combined, forming multi-layered closings interleaved by a layer of air, either without or with a sound-absorbing material between them. The results show that it is necessary to check the effectiveness of each type of fastening of the closing systems because, for example, for the frequency range between 500 and 2,000 Hz, the sound transmission loss of a closing system consisting of cementitious plate with glass wool and line-punctual and punctual-punctual connections exceeds in 6.25% the sound transmission loss of the same system with line-line fastening. For a system composed of expanded polystyrene with glass wool, the sound transmission loss provided by line-line fastening exceeds in 7.0% the sound transmission loss of the same closing system with line-punctual and punctual-punctual fastenings.

keywords: multi-layered closing systems, acoustical performance, sound transmission loss, graphical method.

1. Introduction

The steel-structured construction technique has been increasingly applied, leading to projects that present a satisfactory overall performance. However, the fast assembling allowed by the steel-structured constructive systems requires the use of closing systems that have the same characteristics of prefabrication. The use of industrialized closing systems appears as a rational solution. But the choosing of the closing system for an edifice should be carefully made during its design phase because an improper choice may jeopardize the overall efficiency of the building and result in need of future interferences. Given this, it is important to analyze overall performance, including the checking of the thermal, acoustical and luminous comfort provided by the prefabricated panels found on the national market of civil construction (Souza *et al*., 2007).

Despite the advantage of being lighter and more quickly erected than the traditional ones, industrialized closing systems have less mass, so their acoustical insulation capacity is questionable, leading to unfavorable comfort conditions (Garcia, 2004; Souza *et al*., 2007; Roozen *et al*., 2015).

The acoustical comfort of the users of a building is obtained by reducing the noise in its interior to an acceptable level. The application of closing systems that provide an adequate sound transmission loss between environments can contribute to a desirable acoustical insulation.

However, the study of sound transmission across a multi-layered closing is complex, since it involves several parameters. The sound insulation provided by a wall depends on several factors, such as the superficial density of its components, the thickness of the gap between the layers in multi-layered panels, and the existence (or not) of a sound-absorbing material in that gap. And, according to Bies and Hansen (2003), the way the panels are fastened also influences on sound transmission, requiring a preliminary study of the acoustical performance of the closing system, which considers the type of connection used between panels.

In this context, the objective of this paper is to evaluate how the type of fastening of industrialized multi-layered closing panels influences the estimation of the sound transmission loss that occurs across walls consisting of these panels, by applying a simplified graphical method. Closing systems are made up of cementitious plate panels, aerated autoclave concrete, plasterboard and expanded polystyrene. Herein, studied were combinations of these industrial panels, inserted with a layer of air, making up closing systems with multiple layers, without or with a sound-absorbing material between hem. The evaluation also includes single closure systems consisting of massive precast concrete and ceramic brick masonry.

2. Materials and methodology

Sound transmission loss of a closing system may be obtained in laboratory tests or may be estimated by applying a simplified graphical method presented by Bies and Hansen (2003) and Bistafa (2006), which is based on the study of Sharp (1973). For multi-layered closing systems, this study considers the type of material of the panels used to fabricate the wall, the thickness of the air gap between them, the existence or not of a sound-absorbing material in the gap, as well as how the panels are fastened to each other.

2.1 Calculating the sound transmission loss

Sound transmission loss (TL), which occurs when the sound reaches the other side of a wall with a smaller intensity than the original, is a characteristic of the sound insulation provided by the closing system, and may be an indicator of its acoustic performance (Bies and Hansen, 2003; Bistafa, 2006). Gerges (2000) presents Eq. (1), called the Law of Mass.

$$TL = 20\log(f \cdot M) - 47.4 \quad \text{(dB)} \tag{1}$$

where *f* is the frequency of the incident sound (Hz); *M* is the superficial density of wall material (kg/m²).

In a single-layered wall, the sound transmission loss is influenced by the frequency of the incident sound (f) and shows different resonance and vibration behaviors as per its mass and stiffness. Sound transmission loss across an isotropic panel (solid and homogeneous) may be obtained by standardized tests or may be estimated from the critical frequency (f_c) of an idealized model consisting of a panel of dimensions a, b and h, bending stiffness B_s, and modulus of elasticity E, using the Eq. (2) (Figures 1 and 2) (Bistafa, 2006).

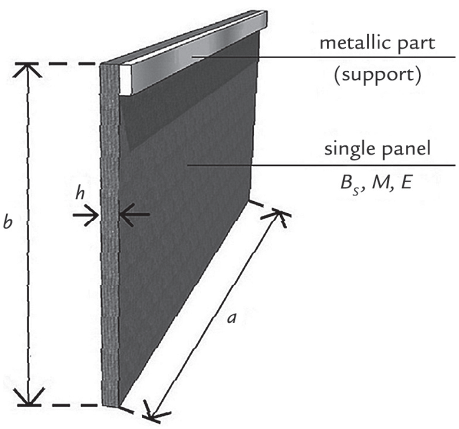

Figure. 1
Idealized model of a simply supported isotropic panel (Ribas, 2013).

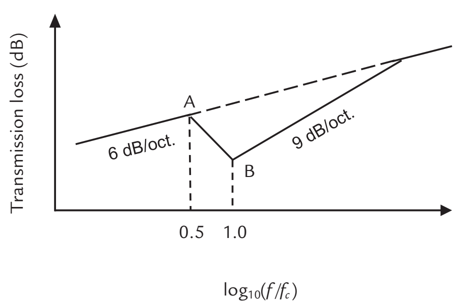

Figure 2
Estimation of the TL across single isotropic panels (Bies and Hansen, 2003).

$$f_c = \frac{c^2}{2\pi}\sqrt{\frac{M}{B_s}} \quad \text{(Hz)} \quad \text{and} \quad B_s = \frac{Eh^3}{12} \quad \text{(N.m)} \tag{2}$$

where f_c is the critical frequency of the panel (Hz); *c* is the speed of sound in the air (m/s); *M* is the superficial density of the panel material (kg/m²); B_s is the bending stiffness of the panel (N.m); *E* is the modulus of elasticity of the panel material (N/m²), and h is the thickness of the panel (m).

Points A and B have coordinates (0.5 f_c; TL_A) and (f_c; TL_B), respectively, which are calculated by the Equation (3).

$$TL_A = 20\log(f_c.M) - 54 \text{ (dB)} \quad \text{and} \quad TL_B = 20\log(f_c.M) + 10.\log\eta - 45 \text{ (dB)} \quad (3)$$

where η is the panel internal damping factor (dimensionless). The TL from point B and f_c is given by Equation (4), valid for $f > f_c$, applied up to the frequency for which the TL is equal to that calculated using the law of mass or Equation (1).

$$TL = 20\log(f \cdot M) + 10\log\left(\eta\frac{f}{f_c}\right) - 45 \quad \text{(dB)} \quad (4)$$

Double-walled closing systems may produce a sound insulation greater than single-walled ones with the same thickness (Figure 3). Due to the complexity of the sound energy transmission ways between the panels, the soundproofing is not equivalent to the sum of the individual acoustic insulations. Bies and Hansen (2003) and Bistafa (2006) present a simplified graphical method, based on the analysis of Sharp (1973), for estimating the sound transmission loss across multi-layered walls, which considers the effects of the way the panels are fastened, which is determinant on their sound transmission efficiency.

This graphical method consists in determining the coordinates of points A, B and C, by means of Equation 5 to 11 (Table 1), and estimating the coordinates of point A' (Figure 4). In the formulation, the numeral 1 is associated with the panel that has the lowest critical frequency, and this frequency is, at most, equal to the critical frequency of the other panel, to which is associated the numeral 2 (Bies and Hansen, 2003; Bistafa, 2006).

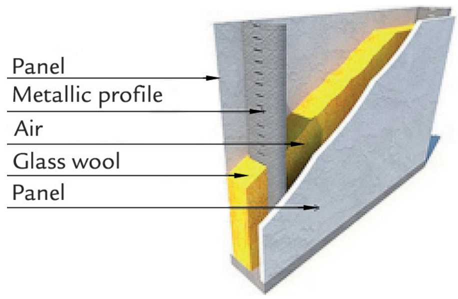

Figure 3
Diagram of the closing systems with sound-absorbing material (Ribas, 2013).

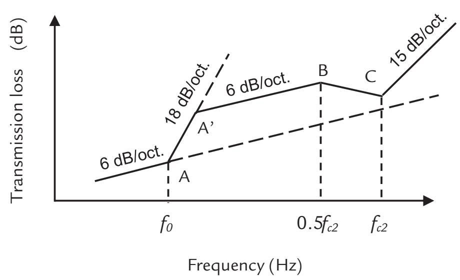

Figure 4
Estimation of TL across double walls (Bies and Hansen, 2003).

The two panels can be fastened to the same rafter or metallic profile, by means of resilient bars in order to reduce the transmission of mechanical vibrations. There are two usual ways of fastening, which generate four possible combinations. When the panel is fastened directly to the rafter or metallic profile, a line of contact between these two elements is generated, forming the so-called in-line fixation (Figure 5a). Fastening by means of resilient bars is called punctual fixation and the bars are attached to the rafters or metallic profiles by means of screws (Figure 5b). The spacing between the rafters or profiles (b_c) are supposed to be uniform and the spacing between screws (e) are supposed to be uniform too. The four possible combinations of fixing are line-line (LL), line-punctual (LP), punctual-line (PL), and punctual-punctual (PP), where the first panel is the one with the lower critical frequency (Bies and Hansen, 2003; Bistafa, 2006).

In Table 1, f_0 is the lowest resonant frequency (Hz); TL_i is in sound transmission loss at point *i* (dB); *d* is the spacing between the panels or the gap thickness (m); *Mi* is the superficial density of panel *i* (kg/m²); f_{ci} is the critical frequency of panel *i* (Hz); b_c is the spacing between rafters in in-line fastening (m); *e* is the spacing between screws in punctual fixing (m), and η*i* is the internal damping factor of the material of the panel *i*.

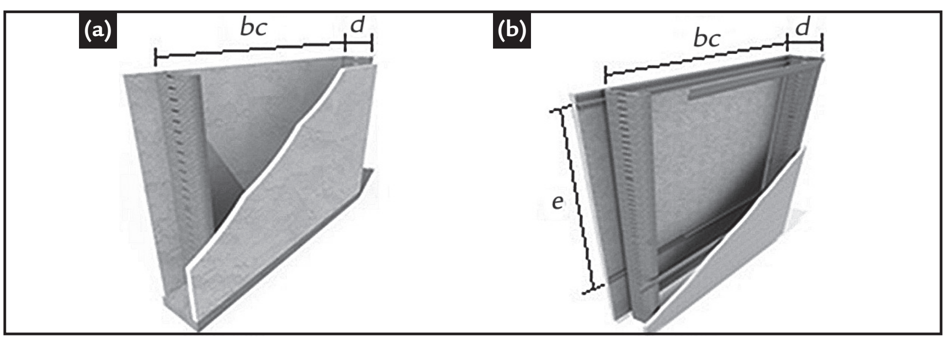

Figure 5
Fastening the panels: in-line (a) and punctual (b) (Bistafa, 2006; Ribas, 2013).

Table 1
Coordinates of points A, B and C (Figure 4)

Point and coordinates	Equations	
A $(f_0\,;\,TL_A)$	$f_0 = 80\left(\dfrac{M_1 + M_2}{dM_1M_2}\right)^{1/2}$ $\quad TL_A = 20\log(M_1 + M_2) + 20\log f_0 - 48$	(5)
B $(0{,}5\,f_{c2}\,;\,TL_B)$	a) When there is no sound - absorbing material in the gap, TL_B is equal to TL_{B1}: $TL_{B1} = TL_A + 20\log\left(\dfrac{fc_1}{f_0}\right) - 6$	(6)
	b) When there is a sound - absorbing material in the gap, TL_B is given by the highest value between TL_{B1} and TL_{B2}, TL_{B2} being: i) line-line fastening: $TL_{B2} = 20\log M_1 + 10\log b_c + 30\log f_{c2} + 20\log\left[1 + \dfrac{M_2 f_{c1}^{1/2}}{M_1 f_{c2}^{1/2}}\right] - 77$	(7)
	ii) line-punctual fastening: $TL_{B2} = 20\log M_1 e + 40\log f_{c2} - 9$	(8)
	iii) punctual-punctual fastening: $TL_{B2} = 20\log M_1 e + 40\log f_{c2} + 20\log\left[1 + \dfrac{M_2 f_{c1}}{M_1 f_{c2}}\right] - 105$	(9)
C $(f_{c2}\,;\,TL_C)$	1. For $f_{c2} \neq f_{c1}$: $\quad = TL_B + 10\log\eta_2 + 6$	(10)
	2. For $f_{c2} = f_{c1}$ $\quad TLc = TL_B + 10\log\eta_2 + 5\log\eta_1 + 6$	(11)

2.2 Evaluating the acoustical performance and panels studied

The closing panel capacity of loss in sound transmission is adopted as a criterion of acoustical performance. Standard NBR 15575 (ABNT, 2013) recommends the following minimum values of sound transmission loss between environments of a building (Table 2).

The panels under study were made of cementitious board (PLC), plasterboard (GEA), aerated autoclave concrete (CCA), expanded polystyrene panels (EPS), massive precast concrete (PMC) or masonry (ATC), and these materials' characteristics are shown in Table 3. Each panel is referred to by its material's initials followed by its thickness in mm between parentheses.

Table 2
Minimum values of sound transmission loss between environments of a building

Element	*TL* (dB)
Wall between autonomous housing units (gemination wall), where there is no dormitory; blind wall dormitories between a housing unit and common areas of potential transit of people (hallways and stairways); and set of walls and doors of distinct units separated by the lobby	45 – 49
Wall between autonomous housing units (gemination wall), where there is at least one dormitory; and blind wall between a housing unit and common areas where people may stay	50 – 54
Blind wall of rooms and kitchens between a housing unit and common areas of potential transit of people, like hallways and stairways	35 – 39

Multi-layered closings with and without glass wool (LVI) as sound-absorbing material in the air gap are presented in Table 4. The thickness of the gap (*d*) is equal to 0.075m and the distances between the rafters (b_c) and between screws (e) are both equal to 0.60 m. The coordinates of the points A, B and C, as shown in Figure 4, are calculated in order to draw the sound transmission loss curves as a function of the frequency in the octave band (Table 4), for the three types of fastening (LL, LP and PP). The combination punctual-line was deleted from this study because, from a further analysis, it was detected that the transmission loss associated to it is always less than the one of the combination line-punctual. The coordinates of point A' are graphically determined.

Material	h (m)	ρ (kg/m^3)	E (N/m^2)	η	υ	B_s (N.m)	f_c (Hz)
PLC (10)	0.010	1,330 [1]	1.2x10^8 [1]	0.005	0.20	83	21,158
GEA (12.5)	0.0125	750 [10]	2.0x10^9 [4]	0.006	0.20	1389	3,113
CCA (100)	0.100	500 [10]	1.35 x 10^9 [1]	0.015	0.15	115,090	390
EPS (100)	0.100	960 [4]	2.50 x 10^6 [1]	0.005	0.08	210	12,670
PMC (100)	0.100	2,400 [10]	2.30 x 10^{10} [1]	0.020	0.20	1,996,528	205
ATC (150)	0.150	1,890 [10]	1.62 x 10^{10} [4]	0.005	0.15	4,661,125	146

Table 3
Characteristics of the materials of the panels.

PLC(10)-air(75)-PLC(10)	PLC(10)-air(75)-GEA(12.5)	CCA(100)-LVI(50)-air(25)-PLC(10)
PLC(10)-LVI(50)-air(25)-PLC(10)	PLC(10)-LVI(50)-air(25)-GEA(12.5)	CCA(100)-air(75)-GEA(12.5)
GEA(12.5)-air(75)-GEA(12.5)	PMC(75)-air(75)-PLC(10)	CCA(100)-LVI(50)-air(25)-GEA(12.5)
GEA(12.5)-LVI(50)-air(25)-GEA(12.5)	PMC(75)-LVI(50)-air(25)-PLC(10)	EPS(100)-air(75)-PLC(10)
CCA(100)-air(75)-CCA(100)	PMC(75)-air(75)-GEA(12.5)	EPS(100)-LVI(50)-air(25)-PLC(10)
CCA(100)-LVI(50)-air(25)-CCA(100)	PMC(75)-LVI(50)-air(25)-GEA(12.5)	EPS(100)-air(75)-GEA(12.5)
EPS(100)-air(75)-EPS(100)	CCA(100)-air(75)-PLC(10)	EPS(100)-LVI(50)-air(25)-GEA(12.5)
EPS(100)-LVI(50)-air(25)-EPS(100)		

Table 4
Composition of the multi-layered panels evaluated, and coordinates of points A, B and C.

3. Results and analysis

The results are shown in the charts of Figures 6 to 13. In Figures 6 to 9 are shown the results for closings without and with glass wool, in which the two closing panels are equal ($f_{c2} = f_{c1}$). In Figure 10 to 13 are shown the results for closings with glass wool only, in which the first panel is different from the second ($f_{c2} \neq f_{c1}$).

Closing systems without a sound-absorbing material (glass wool) present, for the three types of fastenings (LL, LP and PP), the same sound transmission loss curve. When glass wool is added, a change in behavior of the curve occurs according to the kind of fastening (Table 4, Figures 6 to 9). For the closings consisting of multi-layers of cementitious board, plasterboard and expanded polystyrene, the sound transmission loss values rise with the use of glass wool (Figures 6, 7 and 9).

For closing of cementitious plate, the sound transmission loss rises to values above those provided by precast concrete and ceramic brick masonry closings (Figure 6). LP and PP fastenings provide the highest values of sound transmission loss.

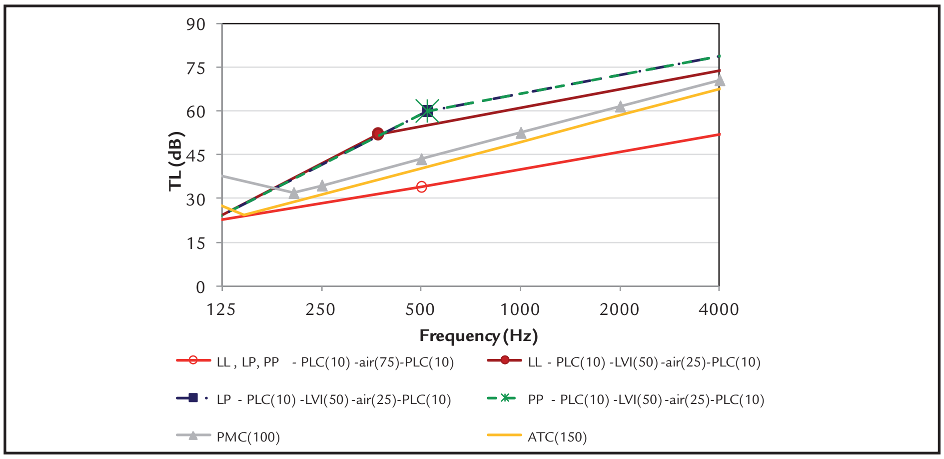

Figure 6
TL as a function of frequency – PLC without and with LVI (LL, LP, PP), PMC and ATC.

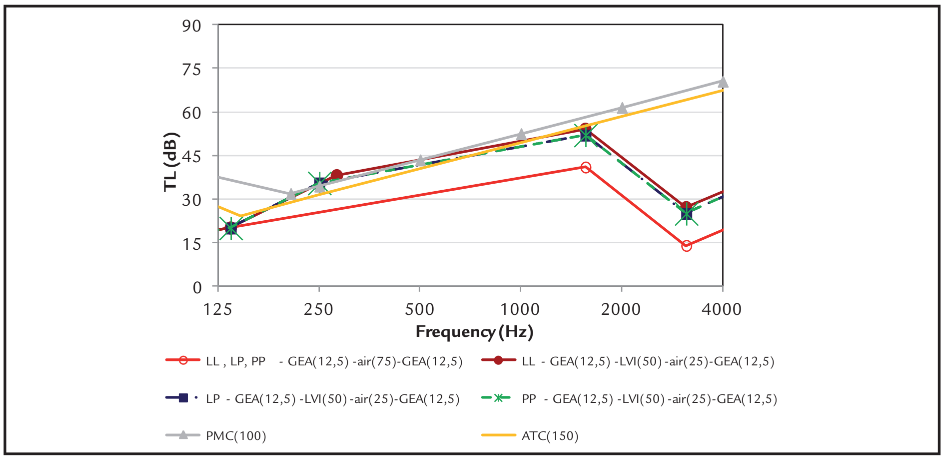

Figure 7
TL as a function of frequency – GEA without and with LVI (LL, LP, PP), PMC and ATC.

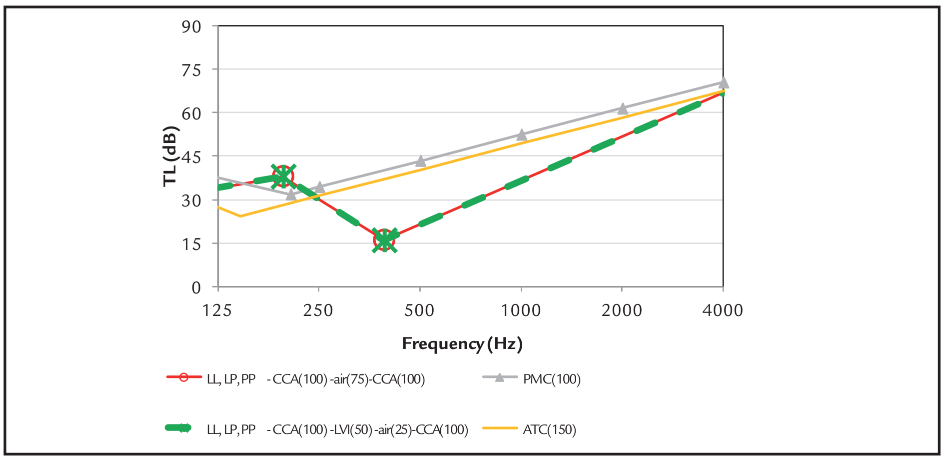

Figure 8
TL as a function of frequency – CCA without and with LVI (LL, LP, PP), PMC and ATC.

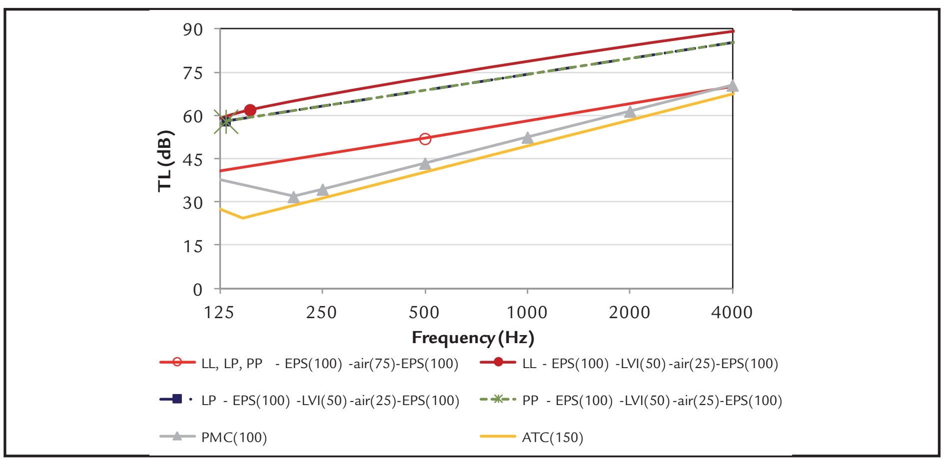

Figure 9
TL as a function of frequency – EPS without and with LVI (LL, LP, PP), PMC and ATC.

For the plasterboard closing, the sound transmission loss rises to values close to those obtained for the precast concrete and ceramic brick masonry closings (Figure 7). The expanded polystyrene closing provides the highest values of sound transmission loss, especially when the fastening is LL (Figure 9).

The sound transmission loss curves for cementitious plate, plasterboard and expanded polystyrene closings, in the frequency range of 500 to 2,000Hz, are completely or mostly in the region controlled by the law of mass (Figure 6, 7 and 9). For the closing of aerated autoclave concrete, neither the kind of fastening nor the use of glass wool influence the values of the transmission loss, which, in the frequency range considered, are below the values obtained for the precast concrete and ceramic brick masonry closings, and are still in the region controlled by coincidence (Figure 8).

For the same frequency range, most of the closings analyzed here comply with the criterion recommended by the standard NBR 15575 (ABNT, 2005) for sound transmission loss, which will be higher than 35 dB (Table 2). The closings that do not meet the standard are composed of plasterboard without glass wool, at 500Hz and 2,000Hz frequencies (Figure 7), and aerated autoclave concrete with and without glass wool, at 500Hz (Figure 8); both for all types of fastenings. The highest sound transmission loss value obtained was 80dB at 1,000Hz, for the LL-fastened closing of expanded polystyrene with glass wool. This transmission loss was higher than the ones provided by LP and PP closings in 5dB (Figure 9). The closing of cementitious plate with glass wool also provides a high value of sound transmission loss (65dB at 1,000Hz, with LP and PP fastenings, which is 5dB higher than that with the LL fastening) (Figure 6), with the advantage of being thinner (95mm) than the closing of expanded polystyrene (275mm).

For the multi-layered mixed closing composed of cementitious plate and plasterboard, with glass wool (Figure 10), the line-punctual fastening provides the highest values of sound transmission loss. These values are closer to the values provided by the non-mixed cementitious plate closing than the ones obtained with the non-mixed plasterboard (Figures 6 and 7).

The aerated autoclave concrete closing, when applied with cementitious plate or with plasterboard, provides sound transmission loss values higher than the aerated autoclave concrete non-mixed closing and, besides, may have its thickness reduced from 275mm to 185mm (Figure 11). At 1,000Hz, the highest value of sound transmission loss, 72dB, is provided by the closing of aerated autoclave concrete mixed with cementitious plate, and with line-punctual fastening (Figure 11).

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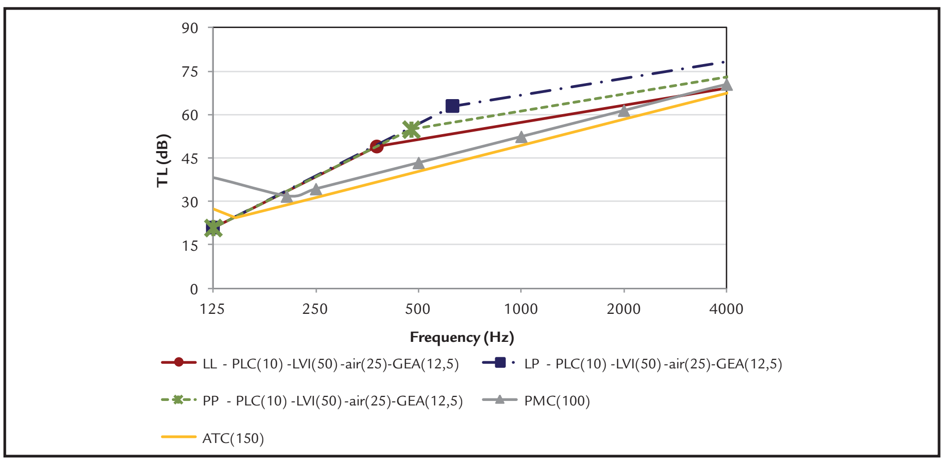

Figure10
TL as a function of frequency – PLC-GEA with LVI (LL, LP, PP), PMC and ATC.

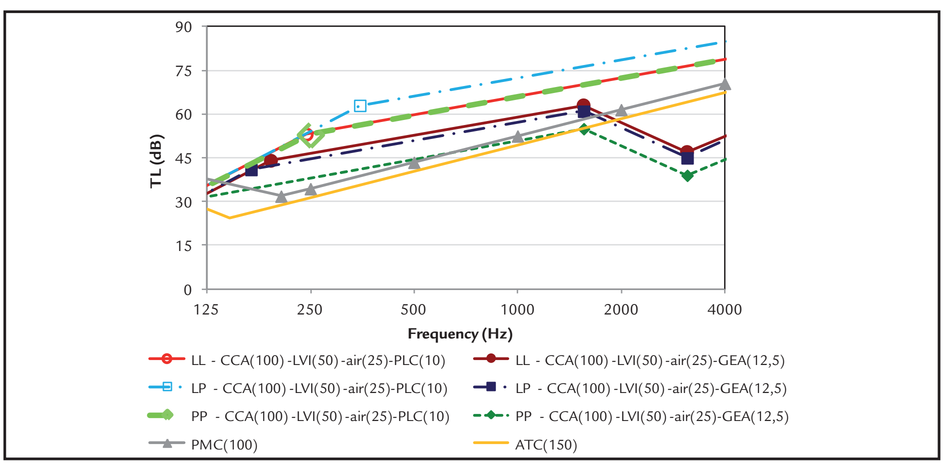

Figure 11
TL as a function of frequency – CCA-PLC, CCA-GEA with LVI (LL, LP, PP), PMC and ATC.

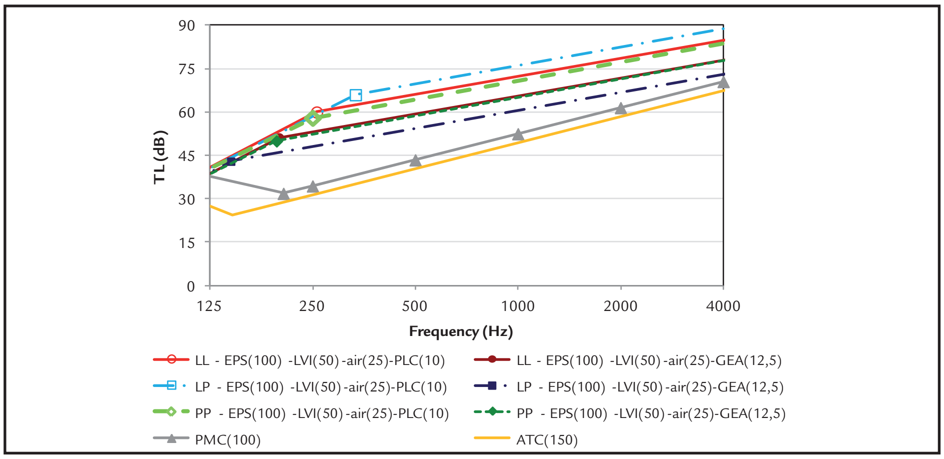

Figure 12
TL as a function
of frequency – EPS-PLC, EPS-GEA
with LVI (LL, LP, PP), PMC and ATC.

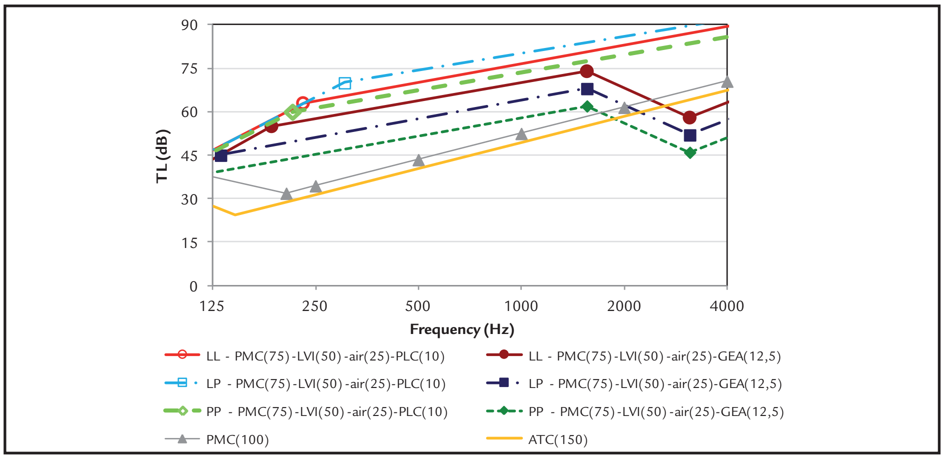

Figure 13
TL as a function
of frequency – PMC-PLC, PMC-GEA
with LVI (LL, LP, PP), PMC and ATC.

The expanded polystyrene closing, when applied with cementitious plate or with plasterboard, provides sound transmission loss values lower than the expanded polystyrene non-mixed closing. Such decrease – 7dB for line-line fastening, at 1,000Hz – may be considered low, but, when mixed, the closing may also have its thickness reduced from 275mm to 185mm, as well (Figure 9 and 12). At 1,000Hz, the highest value of sound transmission loss, 77dB, is provided by the closing of expanded polystyrene mixed with cementitious plate, and (Figure 12).

When mixed with cementitious plate, the multi-layered precast reinforced concrete closing provides sound transmission loss values higher than when single, across all the frequency range considered, from 125 to 4,000Hz. When it is applied with plasterboard, punctual-punctual fastening and higher frequencies, the sound transmission loss stays in the region of coincidence and is lower. In this case, the highest sound transmission loss value, 80dB at 1,000Hz, is provided by the precast concrete closing mixed with cementitious plate, also with line-punctual fastening (Figure 13).

4. Final considerations

For most closings, the line-punctual fastening provides the highest values of sound transmission loss, followed by the punctual-punctual and the line-line fastenings (Table 5). It is necessary to analyze each multi-layered closing system and its behavior as per the three types of fastenings. For example, for the frequency range between 500 and 2,000Hz, sound transmission loss provided by a cementitious plate closing with glass wool and line-punctual punctual and punctual-punctual fastening excels in 6.25% the sound transmission loss obtained by the same system with a line-line fastening; for a closing composed of expanded polystyrene with glass wool, the sound transmission loss provided by the line-line fastening exceeds in 7.0% the sound transmission loss given by the same closing with line-punctual or punctual-punctual fastening.

Considering this same frequency range, in mixed closings, cementitious plate combinations with plasterboard, and cementitious plate with aerated autoclave concrete, expanded polystyrene and concrete precast, with line-punctual fastening, provide sound transmission loss values higher than the other fastenings, and the largest difference occurs with aerated autoclave concrete (7%). It should be noted that when used with cementitious plate or plasterboard the aerated autoclave concrete closing improves its acoustical performance. At 1,000Hz, this mixed closing provides a sound transmission loss 35dB (or 48%) higher than the one provided by the same closing when non-mixed.

This study found that it is possible to raise the sound transmission loss of a multi-layered closing system by placing a sound-absorbing material in the air gap between panels and modifying the way the panels are fastened. The results obtained make it possible to carry out a previous assessment of acoustical performance of a closing system in terms of its sound transmission loss.

Table 5
Maximum values of TL depending on the type of fastening, at the frequency of 1,000Hz

Closing system	TL (dB) at 1,000Hz			Closing system	TL (dB) at 1,000Hz		
Type of fastening →	LL	LP	PP	Type of fastening →	LL	LP	PP
PLC(10)-air(75)-PLC(10)	39	39	39	PLC(10)-LVI(50)-air(25)-GEA(12.5)	57	67	62
PLC(10)-LVI(50)-air(25)-PLC(10)	62	67	67	CCA(100)-LVI(50)-air(25)-PLC(10)	67	72	67
GEA(12.5)-air(75)-GEA(12.5)	37	37	37	CCA(100)-LVI(50)-air(25)-GEA(12.5)	59	57	50
GEA(12.5)-LVI(50)-air(25)-GEA(12.5)	49	47	47	EPS(100)-LVI(50)-air(25)-PLC(10)	72	77	70
CCA(100)-air(75)-CCA(100)	37	37	37	EPS(100)-LVI(50)-air(25)-GEA(12.5)	65	61	65
CCA(100)-LVI(50)-air(25)-CCA(100)	37	37	37	PMC(75)-LVI(50)-air(25)-PLC(10)	77	82	73
EPS(100)-air(75)-EPS(100)	58	58	58	PMC(75)-LVI(50)-air(25)-GEA(12.5)	70	64	58
EPS(100)-LVI(50)-air(25)-EPS(100)	80	75	75				

5. Acknowledgments

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