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EVALUATION OF THE ACOUSTIC PERFORMANCE OF LIGHTWEIGHT STEEL-FRAMED FACADE WALLS

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ABSTRACT

Lightweight steel-framed (LSF) constructive system has become increasingly popular both in new buildings and in refurbishments. Due to LSF buildings usual low mass and rigid connections between the outer and the inner sheathing of the walls, some acoustic performance drawbacks can emerge. In this work, the influence of the steel frame in sound insulation performance of LSF façade walls is studied. For this purpose, several LSF walls types are assessed, namely cold, warm and hybrid constructions. The assessment of the thermal behaviour and sound insulation is performed using Sharp model with some modifications.

RESUMO

O sistema construtivo composto por estrutura de aço enformado a frio (LSF) tem vindo a tornar-se progressivamente mais utilizado nos últimos anos, quer em novos edifícios, quer em trabalhos de reabilitação. Do ponto de vista funcional, designadamente no que concerne ao desempenho acústico, este sistema pode apresentar algumas desvantagens, em comparação com o sistema construtivo tradicional, pelo facto de apresentar uma reduzida massa e as ligações entre os painéis serem rígidas. Neste trabalho a influência da estrutura de suporte deste sistema construtivo composta por perfis metálicos é avaliada do ponto de vista do isolamento de fachada. Com este propósito são avaliados três tipos de soluções LSF utilizadas normalmente em fachadas, nomeadamente as estruturas frias, quentes e hibridas. A avaliação do isolamento conferido por estas soluções é efetuado com recurso ao modelo de Sharp com algumas alterações.

1. INTRODUCTION

Over the last few years, alternatives to the traditional constructive method have been emerging and proliferating. The lightweight steel-framed (LSF) constructive system is an example of this new and growing trend that has been attracting interest worldwide. LSF buildings register a wide use over the USA, Australia and Japan and are gaining market share in Europe as well [1].

Throughout the literature regarding the acoustic performance of lightweight construction systems, LSF walls are usually addressed as double walls. The sound transmission of LSF and wood studs double walls has been investigated and described over the past decades. A literature review of sound transmission models of double walls with connections between the inner and the outer panel can be found in [2], [3]. Moreover, an assessment of the most referenced simplified methods of sound transmission provided by double walls was presented by Hongisto [4]. This work has shown that there is a large discrepancy between the results given by the different methods and only five of the seventeen considered models can deal with connections between panels. One of these models was presented by Sharp in 1978 [5], being currently widely used in the prediction sound transmission loss of lightweight building elements. Sharp model with some modifications will be the reference for the present work.

The influence of several parameters on the sound insulation of lightweight double walls has been studied by different researchers by means of measurements. Focusing on the effect of the studs, several parametric studies were performed including the stud size, spacing, geometry, and absorbing material in the air gap. A report provided by Warnock [6] displays several measurements and estimations of sound transmission class (STC) for a large variety of both interior and exterior steel framing double walls. According to the literature, the number and the type of studs, as well as the distance between them, are factors that influence sound insulation performance of a lightweight double wall. The actual acoustic response of LSF façade walls highly depends on the mechanical properties (mainly stiffness) of the steel studs [2].

Recently, some computer programs that are based on scientific theories have been made available allowing to predict sound transmission loss provided by multi-layered structures, such as INSUL software [7]. Kurra [8] has performed a comparison of some computational tools, including INSUL software [7] investigating the differences and similarities of the obtained results through a sampling study. This work also presents a comparison between the calculated and measured data, in which INSUL has shown a better correlation with the experimental results. However, the performed verification with measured data did not contemplate LSF partitions. This software was used to perform the acoustic analysis displayed in present work. As far as the authors know, no other work, besides this, was found regarding the use of INSUL software to evaluate the influence of the steel frame in the acoustic response of LSF façade walls. The sound insulation analysis conducted in the present work focuses on the evaluations assuming direct sound transmission, and therefore flanking sound transmission is not under analysis. Moreover, it will be only accounted for the sound transmission across the opaque LSF wall area. Three typologies of solutions that are used to increase thermal performance are here addressed and compared in what regards acoustic performance.

2. CLASSIFICATION OF LIGHTWEIGHT STEEL-FRAMED ELEMENTS

In the thermal performance framework, LSF elements, e.g. façade walls, can be classified into three typologies, depending on the insulation position: cold, hybrid and warm frame construction. Figure 1 illustrates these typologies as well as the most common components of LSF façade walls: expanded polystyrene (EPS), usually incorporated into the external thermal insulation composite system (ETICS); oriented strand board (OSB); rock-wool (RW); gypsum plasterboard. This LSF elements classification will be further considered throughout this study.

In cold construction (Figure 1 (a)), the totality of the applied insulation, generally a fibrous material, is placed inside the air cavity of the wall (batt insulation), within the thickness of the steel frame, being this insulation layer pierced along its thickness by it. In contrast with cold frame elements, warm frame construction (Figure 1 (c)) is characterized by the application of the insulation exclusively from the outside of the steel frame. As an intermediate solution between the former two, being also the most current edification solution, the hybrid construction (Figure 1 (b)) is characterized by having insulation material outside and in-between the steel frame.

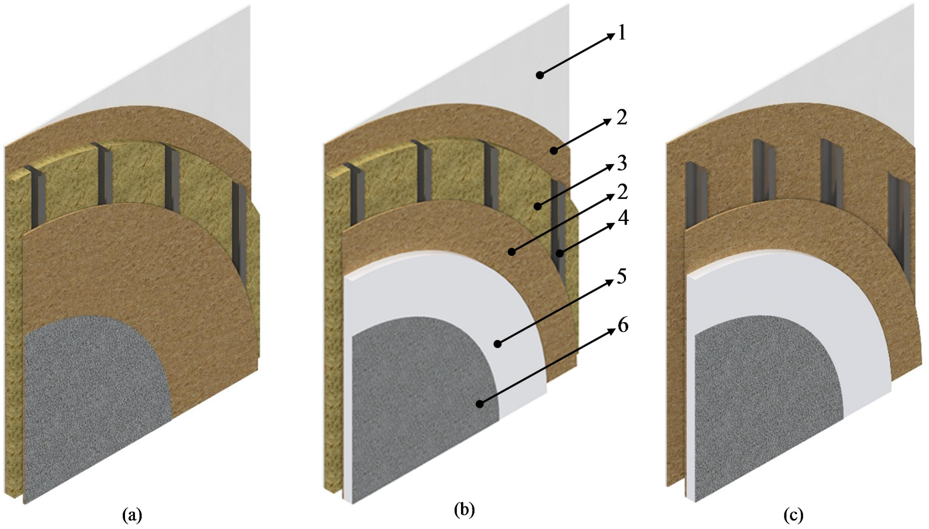


Figure 1: Classification of LSF elements, according to the position of the insulation: (a) cold frame construction; (b) hybrid frame construction; warm frame construction. Materials: 1-Gypsum Plasterboard; 2-OSB; 3-RW; 4-LSF; 5-EPS; 6-ETICS finish.

2. MODEL DESCRIPTION

In this study, three façade walls are under analysis, one for each LSF construction type, as displayed Figure 1. Each wall comprises a steel frame structure composed of a single layer of galvanized cold-formed steel studs with a “C” cross-sectional shape with dimension 150 x 43 x 15 x 1.5 [mm].

Regarding the sound insulation characterization, INSUL software [7] is used, which requires knowledge of several parameters: the thickness and stiffness of the several components of the wall, the dimension of the air cavity, the type of steel stud, corresponding thickness and absorbing properties of the absorbent materials.

Table *1* presents the physical properties of each material assembled in the several studied walls. Sound insulation characterization involves a vaster set of inputs, e.g. elasticity modulus (E), Poisson´s ratio (v), internal damping, density (ρ) and the airflow resistivity (σ) for absorbent materials.

Table 1: Elasticity modulus (*E*) and density (ρ) of the rigid components assembled in the façade walls.

Physical properties	**ETICS finishing**	**EPS**	**OSB** [15mm]	**OSB** [10mm]	**Steel**	**RW**	**Gypsum plasterboard**
E [GPa]	3.000	0.007	5.500[1] 2.200[2]	5.500[1] 2.200[2]	-	-	2.500
ρ [kg.m^{-3}]	1300	20	600	620	-	30	727
v	0.30	0.02	0.30	0.30	-	-	0.27
Internal Damping	0.01	0.01	0.01	0.01	-	-	0.01

[1] longitudinal elasticity modulus; [2] transversal elasticity modulus.

Two values of elasticity modulus (E) are presented for the OSB, being the superior value (E1) de longitudinal elasticity modulus and the inferior one (E2) the transversal elasticity modulus. All elastic materials were assumed isotropic except for OSB layers which were modelled as orthotropic materials due to the significant orthotropic ratio displayed.

In the following analysis the presence of an absorbing material filling the air cavity is studied. A rock-wool with a density of a 30 kg.m-3 is used. Based on the abacus presented by Vigran [9], for this density, an air flow resistivity (σ) of 9300 Pa.s.m-2 is assumed.

Regarding the sound insulation characterization, provided by INSUL software [7], it is indicated by the software developer that the margin of error within Rw ± 3 dB can be expected. In the sound insulation characterization analysis, it was assumed that the façade wall measures 2.7 m length per 3.6 m high, being exposed to a random sound field. The size of the panel can influence the measured sound transmission loss. INSUL software [29] predicts this effect using an expression developed by Sewell [37], which was taken into account during the calculations. The software also accounts for the energy loss that occurs at the edge of a normal surrounding structure, by means of the edge damping factor. This effect is significant for heavy partitions in normal constructions [38]. As the study focus on lightweight partitions, edge damping was neglected during the study.

3. ACCURACY VERIFICATION

As no previous research work was found on the use INSUL software [7] regarding the sound insulation characterization of LSF façade walls, the authors evaluated the accuracy of the software for the intended goal. For this purpose, experimental results of sound insulation characterization of LSF walls [40], measured in the laboratory facilities of Institute for Research and Technological Development in Construction, Energy, Environment and Sustainability (ITeCons, Portugal) and also presented by the Portuguese gypsum boards company Gyptec Iberian [10], were compared with INSUL results. The experimental measurements were performed with LSF walls, where the gypsum plasterboard is the only sheathing material. Several solutions were tested, with a different number of sheathing layers on each side of the wall (Interior and Exterior) and several air cavity dimensions and fillings.

The layouts and materials used for the former measurements were replicated in INSUL software. The required physical properties were those referring to the tested gypsum plasterboards (Table 2) and mineral-wool (MW) as well as the respective thicknesses. Furthermore, although the orthotropic ratio of the gypsum plasterboard does not differ much from the unitary value, this material was modelled as orthotropic.

Table 2: Physical proprieties of the gypsum plasterboard used in the accuracy verification of INSUL software.

Longitudinal elasticity modulus	**Transversal elasticity modulus** [GPa]	**Poisson´s ratio**	**Density** [kg.m^{-3}]	**Internal damping**
2.800	2.200	0.27	625	0.01

For the cavity filling, a 70 kg.m^{-3} density mineral-wool with an air flow resistivity of 33000 Pa.s.m^{-2} [9] was used. Throughout all the verification cases, 12.5 mm thick gypsum pasteboards were considered. A steel frame composed by 0.5 mm thick steel studs with a "C" cross-sectional shape, spaced 600 mm every two studs, was modelled. Note that these properties of the partition were well described in [10]

From the available experimental data, a set of representative solutions was chosen for reference on the accuracy verification (A1-A10). In this sense, Table 3 displays the constructive details of the analysed solutions, namely: the dimension of the air cavity, ranging from 48 mm to 125 mm; the number of gypsum plasterboard layers on each side of the partition (between 1 and 3 layers); thickness of the mineral-wool in the air-cavity.

Table 4 displays the results of the accuracy verification analysis, by means of the weighted sound reduction index (Rw) and spectrum adaptation terms (C; Ctr). Furthermore, the differences between the experimental measurements and the values obtained from INSUL are also presented and analysed.

Table 3 – Overview of the modelled cases for accuracy verification of INSUL software.

Model	Dimension of the air cavity					Nº. of layers	Nº. of layers	Absorbing material
	48 [mm]	**70** [mm]	**90** [mm]	**100** [mm]	**125** [mm]	**Int. side** [un.]	**Ext. side** [un.]	**MW** [mm]
A1	✓					1	1	0
A2	✓					2	2	0
A3		✓				1	2	50
A4				✓		1	1	60
A5				✓		2	2	60
A6				✓		3	3	60
A7					✓	1	1	60
A8			✓			1	1	60
A9			✓			2	2	60
A10			✓			3	3	60

Table 4 – Results of the INSUL accuracy verification analysis against experimental measurements.

Verification Cases	INSUL [dB]			Experimental [dB]			Δ (Exp. – INSUL) [dB]		
	R_w	C	C_{tr}	R_w	C	C_{tr}	R_w	C	C_{tr}
A1	34	-3	-7	33	-2	-7	-1	1	0
A2	42	-3	-10	40	-3	-7	-2	0	3
A3	46	-4	-12	47	-6	-12	1	-2	0
A4	44	-5	-12	46	-5	-11	2	0	1
A5	54	-3	-10	51	-5	-11	-3	-2	-1
A6	60	-3	-8	56	-4	-10	-4	-1	-2
A7	45	-4	-11	47	-5	-11	2	-1	0
A8	43	-5	-12	45	-5	-11	2	0	1
A9	54	-4	-11	51	-5	-11	-3	-1	0
A10	60	-3	-9	55	-4	-10	-5	-1	-1

Being aware of the error margin announced by the software developer regarding the Rw value (± 3 dB), the obtained results are in accordance with that tolerance. It can also be noticed that INSUL tends to provide higher Rw values than the experimental measurements.

It was found that the use of internal damping of 0.01 for the gypsum plasterboard provides a better agreement between the measurements and the INSUL results, rather than assuming an superior value usually suggested in the bibliography [11] [12] for this material, which indicates a value of approximately 0.02.

Despite this good agreement, it can be seen in Table 4 that when it comes to triple layer of similar mass sheathing, the Rw values differ 4 dB (A6) and 5 dB (A10). According to the software developer [7], the accuracy seems to decrease as a function of the number of elements involved in the construction. Therefore, for a triple panel construction, the accuracy is considerably less than for single and double panel constructions. In these situations, based on INSUL predictions against laboratory tests, a 4 dB difference for the Rw value can be found [38], which matches the obtained results. However, the models under study in this work do not resemble triple layer panels scenarios with similar mass.

4. SOUND INSULATION PERFORMANCE

In the present section, the weighted sound reduction index (Rw) will be discussed for the three different configurations.

In Figure 2(a) the weighted sound reduction indexes obtained for LSF cold frame construction with and without the steel studs are presented. It can be observed how the rock-wool efficiency can be significantly impaired due to the presence of the steel frame. The greater the insulation thickness in the air cavity is, the greater is the loss of efficiency of this component. Increases from 10% (Model C1) up to 19% (Model C6) of the Rw were reached when comparing the sound insulation performance of the wall with and without the steel frame.

It also can be noticed in Figure 2 (a), that increasing the rock-wool thickness from 25 mm to 150 mm only increased the Rw value by 1 dB. On the other hand, neglecting the presence of the frame, the same increase led to a raise of 6 dB, evidencing once again the loss of effectiveness of the batt insulation. This is consistent with the experimental data presented by Paul et al. [3].

In practical terms, from the acoustic performance perspective, the absence of the steel studs could be associated to double studs LSF walls. In this constructive solution, there are no rigid connections between the outer and the inner panels of the wall and the batt insulation is not short circuited by the frame. Although double stud LSF walls are more expensive and more space consuming than single studs façade walls, the application of batt insulation in double studs walls is much more effective, leading to an increase of sound insulation performance; which keeps rising when the thickness of cavity filling increases.

It was also computed the Rw value of a cold type LSF façade wall with and without any rock-wool. Without phonoabsorvent material and assuming the presence of the steel frame a Rw value of 48 dB was obtained, which comparing with the C1 model (52 dB), results in a 4 dB difference. This increase is greater than the one which resulted from increasing the rock-wool thickness from 25 mm to 150 mm (1 dB).

The influence of one type of acoustic studs was also briefly addressed, using INSUL software. Note that the thickness of these studs cannot be specified in the software. When modelling C1 configuration with acoustic studs, a Rw value of 56 dB was reached. This change corresponds to an Rw improve of 4 dB, compared with the 1 dB difference obtained by adding more 125 mm of RW.

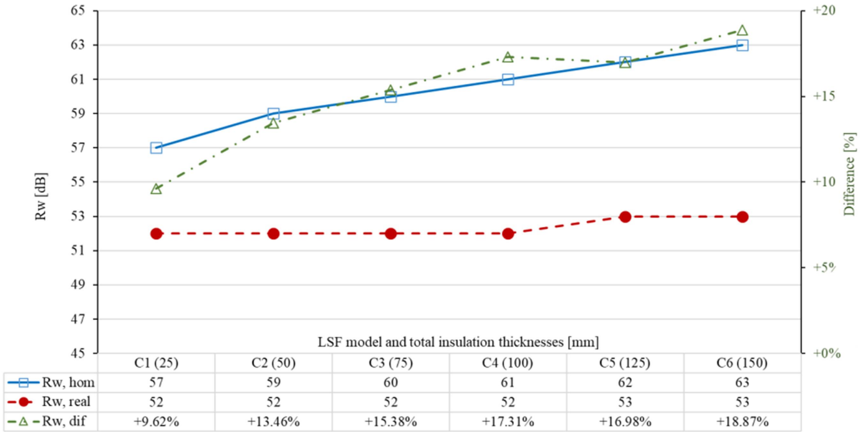
Hybrid façade walls (see Figure 2 (b)), although less severe than in cold frame construction, also reveal that the Rw value is impaired due to the presence of the steel frame, short-circuiting the existing rock-wool. The computed Rw values are the same regardless the thickness of applied acoustic insulation.

The Rw values for the LSF warm construction are presented in Figure 2 (c). Unlike cold or hybrid construction, this constructive type does not have any acoustic insulation in its constitution. It can be noticed from the analysis of Figure 2 (c), that as the EPS thickness increases the Rw value decreases from 48 to 46 dB. This decrease is due to the coincidence effect, regarding the influence of the EPS thickness enlargement, which increases the frequency range where the sound insulation performance drops.

The applied EPS has a density of 20 $kg.m^{-3}$, which is translated in a surface mass of 3 $kg.m^{-2}$ in the model where its thickness is higher (W6). This material, in heavy constructions has an insignificant influence in the façade walls sound insulation performance and can even be neglected in the acoustic performance assessment. On the other hand, in lightweight façade walls, the EPS thickness can influence the Rw value, as shown.

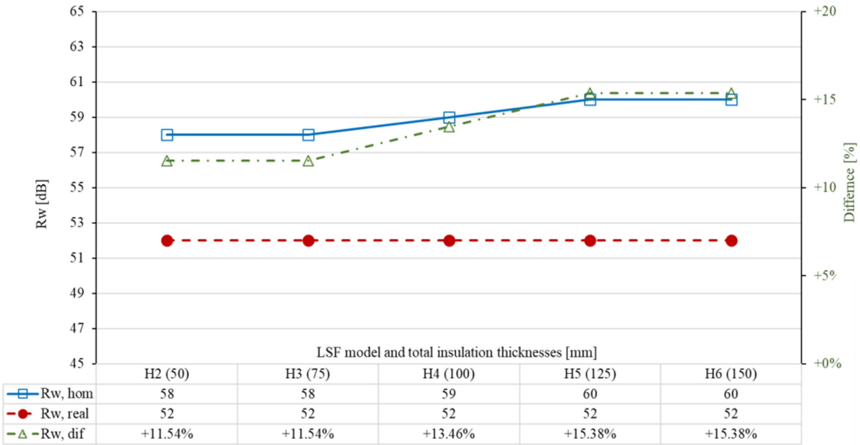
The lack of phonoabsorvent material can be noticed in the obtained sound reduction performance of warm frame walls; the maximum obtained Rw was 48 dB, for W1 model.

As there is no rock-wool being pierced by the steel studs in warm frame walls, the difference between considering the steel studs or neglecting them is not so evident, ranging from 4 % to 7%. This difference is essentially due to the increased rigidity of the system introduced by the steel connections between panels.



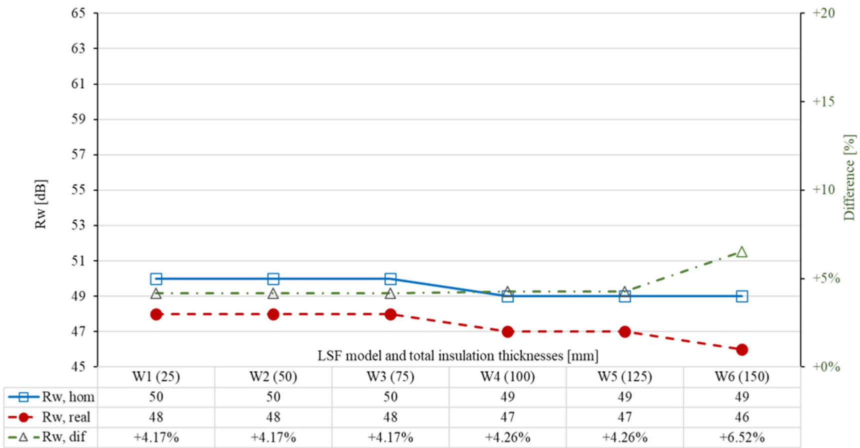
	C1 (25)	C2 (50)	C3 (75)	C4 (100)	C5 (125)	C6 (150)
Rw, hom	57	59	60	61	62	63
Rw, real	52	52	52	52	53	53
Rw, dif	+9.62%	+13.46%	+15.38%	+17.31%	+16.98%	+18.87%

(a)



	H2 (50)	H3 (75)	H4 (100)	H5 (125)	H6 (150)
Rw, hom	58	58	59	60	60
Rw, real	52	52	52	52	52
Rw, dif	+11.54%	+11.54%	+13.46%	+15.38%	+15.38%

(b)



	W1 (25)	W2 (50)	W3 (75)	W4 (100)	W5 (125)	W6 (150)
Rw, hom	50	50	50	49	49	49
Rw, real	48	48	48	47	47	46
Rw, dif	+4.17%	+4.17%	+4.17%	+4.26%	+4.26%	+6.52%

(c)

Figure 2: Weighted sound reduction index (R_w) values obtained for the several LSF walls: a) cold frame; b) hybrid frame; c) warm frame.

5. CONCLUSIONS

In this work a study was performed in order to assess the influence of the steel frame in the sound insulation performance of LSF single stud façade walls. The results were obtained by performing by using a Sharp model with some modifications. It was shown that the steel frame can also significantly affect the sound insulation performance of LSF walls. This influence is more notorious when batt insulation is present (cold and hybrid frame walls). It was seen from the obtained results that not considering the steel frame, the sound insulation of LSF façade walls increases adding some phonoabsorvent material in the air cavity, and keep rising when the thickness of the batt insulation increases. This effect would also be noticeable in double studs LSF walls. On the other hand, it was verified that the structural coupling between the outer and the inner panels is responsible for nullifying this effect. In cold frame walls, when increasing the batt insulation from 25 to 150 mm, and neglecting the steel frame, a 6 dB raise was reached regarding the Rw value. By its turn, considering the steel studs, has only motivated an improvement of 1 dB. Although more discreet, hybrid frame façades follow the same tendencies of cold frame walls. Furthermore, in the cold construction façades framework, filling the empty air cavity with 25 mm of rock-wool has resulted in an increase in the Rw value in 4 dB. By its turn, increasing the batt insulation from 25 to 150 mm has only improved the Rw of the façade wall in 1 dB. In this sequence, it was concluded that the steel frame, providing a rigid connection between the outer and the inner panels of an LSF wall, leads to a significant increase of panel sound radiation efficiency. By presenting the obtained results assuming the presence and neglecting the steel frame, the reached conclusions may be indicative of sound insulation performance of single studs walls and of walls that do not have connections between panels or less rigid ones. As for the influence of the external layer of EPS in the sound insulation performance of LSF walls, it was concluded not only that it does not improve this performance, but that even decreases slightly the Rw value of the wall. This effect is evident in warm frame walls for greater EPS thicknesses.

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