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Development of thermo-acoustic floating floors for use between parking and dwellings

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The French thermal regulation (RT2005) is favoring thermal floating floor between spaces such as parkings or stores, and dwelling units. However, these solutions do not fulfill the French acoustic regulation with regards to airborne noise. This paper discusses the development of solutions allowing fulfilling both the thermal and the acoustic regulation. To achieve this goal, a mixed approach combining measurements and numerical predictions is used. Furthermore, the laboratory characterization of such floating systems usually involves a concrete base floor 140 mm in thickness (following the NF EN 140-8 standard) and a floating concrete layer 40 mm in thickness. However, in situ the concrete base floor as well as the floating concrete layer can be thicker. Therefore, some laboratory measurements were performed on a thermal floating floor system combining a 200 mm thick concrete base floor, a thermal insulation layer (polystyrene or polyurethane based foam for example) and a 60 mm thick floating concrete layer. The prediction method shows that this type of thermal floating systems is not acceptable with respect to the acoustic regulation. The behaviour of such multi-layered systems is investigated using a wave approach based prediction tool in order to develop solutions allowing fulfilling the acoustic regulation.

1 Introduction

The French thermal regulation (RT2005) is favoring thermal floating floor between spaces such as parkings or stores, and dwelling units. However, these solutions do not usually fulfill the French acoustic regulation with regards to airborne noise (see acoustic requirement in Table 1). This paper discusses the development of solutions allowing fulfilling both the thermal and the acoustic regulation.

To achieve this goal, a mixed approach combining measurements and numerical predictions is used. Furthermore, the laboratory characterization of such floating systems usually involves a concrete base floor 140 mm in thickness (following the NF EN 140-8 and EN ISO 140-16 standards [1, 2]) and a floating concrete layer 40 mm in thickness (French historical thickness for such measurement). However, in situ the concrete base floor as well as the floating concrete layer can be thicker. Therefore, some laboratory measurements are performed on a thermal floating floor system combining a 200 mm thick concrete base floor, a thermal insulation layer and a 60 mm thick floating concrete layer. The prediction method shows that this type of thermal floating systems is not acceptable with respect to the acoustic regulation. The behaviour of such multi-layered systems is investigated using a wave approach based prediction tool in order to develop solutions allowing fulfilling the acoustic regulation.

Emission room	Reception room	
	Main room	Kitchen or bathroom
Garage (individual or collective)	55	52
Commercial space or activity rooms	58	55

Table 1 French regulation acoustic requirements for considered situation in terms of D_{nTA} in dB.

2 Models description

A model for infinite multilayered structures is used, based on a transfer matrix approach [3]. The different infinite isotropic layers of constant thickness can be either solid, fluid or porous (following Biot's theory [4]) elements. A computer program (CASC software), based on this approach, has been developed at CSTB and used to predict sound transmission, sound absorption impact noise and rainfall noise of building elements.

For sound transmission prediction, the system is excited by a diffuse acoustic field composed of multiple acoustic plane waves incoming in different directions. A technique based on a spatial windowing of plane waves presented in [5] is used in order to take into account the finite size of a planar structure in sound radiation and sound transmission calculation. This technique leads to prediction results much closer to experimental measurements than the classical wave approach applied to infinite structure. It is a very simple method in the case of sound transmission since the associated radiation efficiency depends only on the spatial window considered (i.e. the size of the structure) and can therefore be pre-calculated.

In the case of impact noise, the structural excitation distributed over a small area of the structure is decomposed into an infinite number of propagating normal stress waves. The velocity field on top and bottom interface, evaluated in the wave number domain, allows calculating the radiated acoustic intensity leading to the impact noise. The impact noise reduction ΔL of the floating floor is then deduced from the impact noise level of the base floor calculated with and without the floating floor. The excitation force associated to the tapping machine can be estimated as explained in reference [6] as a function of the mass and the impact velocity of the hammer, the input mobility of the structure studied and the impact frequency of the tapping machine. Note that the excitation force depends on the input mobility of the system and must be calculated for each system.

For such floating systems, one of the key parameter is the dynamic compressional stiffness s' of the elastic layer. The dynamic stiffness s' of the different resilient layers (thermal and acoustic) considered in this study has been evaluated from a mass-spring resonance frequency, following the standard ISO 9052-1 [7]. The loading mass required in the standard is of 8 kg for samples of dimensions 200x200 mm^2 (i.e. a density per unit area of 200 kg/m^2, corresponding to about 80 mm of concrete). Since it was not representative of the considered floating system, different mass loadings (close to the actual ones) were implemented for this characterization. This dynamic compressional stiffness measurement allows deducing the elastic modulus of the resilient layer considered.

The ACOUBAT software based on the NF EN 12354-1, -2, -3 and -6 standards [8] is used to verify the fulfillment to the French acoustic regulation, based on the measured our predicted performance of the thermal or thermo-acoustic floating floor system.

3 Thermal floating floors

In this section, the performance of thermal floating floors is discussed. The project, reported in this paper, considered three different types of thermal insulation layers: 72 mm thick expanded polystyrene, 70 mm thick extruded polystyrene and 60 mm thick polyurethane based foam. The prediction is based on the measured dynamic stiffness of these layers (a variation of twice the measurement standard deviation is also taken into account).

3.1 Performance on 200 mm base floor

Thermal floating floor systems combining a 200 mm thick concrete base floor, a thermal insulation layer and a 60 mm thick floating concrete layer are considered in this section. The results in terms of acoustic performance ΔR and ΔL are presented in Fig.1 for the expanded polystyrene layer. In the low frequency range (below 400 Hz), the predicted performance with respect to airborne noise ΔR is relatively close to the measured one. Above 500 Hz, the measured performance ΔR remains limited around 10-12 dB; this limitation is related to a transmission path that is not taken into account in the model. It should be noted that this limitation has no influence on the performance global index $\Delta(R_w+C)$. The performance with respect to impact noise ΔL predicted by the model is close to the measured one up to 1250 Hz.

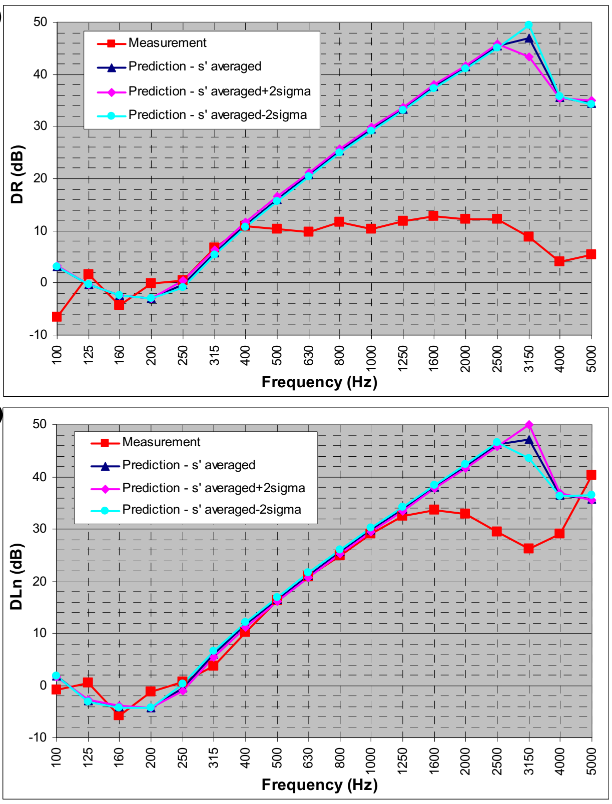


Fig.1 Acoustic performance of thermal floating floor; (a) airborne noise and (b) impact noise.

Table 2 presents the corresponding global acoustic index. It should be noticed that the evaluation of the global index ΔL_w in dB usually calculated for the standard base floor 140 mm in thickness, can not be applied when the performance is obtained on a 200 mm base floor. Therefore, a similar approach as used for the evaluation of the global index $\Delta(R_w+C)$ is preferred. It is noted $\Delta(L_w)$ in dB and is obtained from the difference in L_w of the system with and without floating floor.

Base floor 200 mm – Floating concrete floor 60 mm	Δ(Rw+C) dB	Δ(Lw) dB
Measurement	2	20
Prediction – s' average	0	16
Prediction – s' average+2σ	0	16
Prediction – s' average-2σ	0	16

Table 2 Global acoustic index for thermal floating floor.

It should be observed that the decrease in acoustic performance ΔR and ΔL in the high frequency range (3150-4000 Hz) is related to a compressional wave resonance in the resilient layer ; this resonance occurring when the resilient layer thickness is equal to half the compressionnal wavelength.

Similar results were obtained with the others types of thermal layers considered. In general, the predicted performance is close the measured one. The acoustic performance is different (by 1 dB) depending on the thermal layer considered: as the dynamic stiffness lowers (more resilient layer) the performance increases.

3.2 Performance on 230 mm base floor

Since the comparison between prediction and measurement were found acceptable, the acoustic performance considering a base floor 230 mm in thickness was predicted for the same floating systems.

In general, the acoustic performance with respect to airborne and to impact noise is only slightly modified when the base floor thickness is increased from 200 to 230 mm. However, this increase in thickness induces a slight decrease in performance in the low frequency range; the global index $\Delta(R_w+C)$ is indeed decreased by 1 dB.

3.3 Building performance

Building acoustic performance has to be predicted to validate the building components choice with respect to the French acoustic regulation. Since this work is concerned with a garage or stores as a lower floor, a large 30 m^2 emission room was selected with a 16 cm thick concrete façade. The reception room in the second floor dwelling is relatively small (3x3 m^2) which corresponds to a negative configuration (with respect to a larger room). Interior separating walls are made of standard 50 mm thick honeycomb partition (plasterboards sandwiching a cardboard honeycomb core) with a performance around R_w+C=26 dB. Measured performance on the 200 mm thick base floor is used for the building performance predictions. The effect of two different thermal insulation linings applied on the façade is also considered: the first one noted ESA3 with a performance $\Delta(R_w+C)$ of -3 dB, and the second one ESA5 with a performance $\Delta(R_w+C)$ of 8 dB.

The building geometry and the different acoustic flanking paths are shown in Fig.2. It is commonly assumed that a margin of 1 dB should be taken to select a building solution with respect to acoustic regulation requirement.

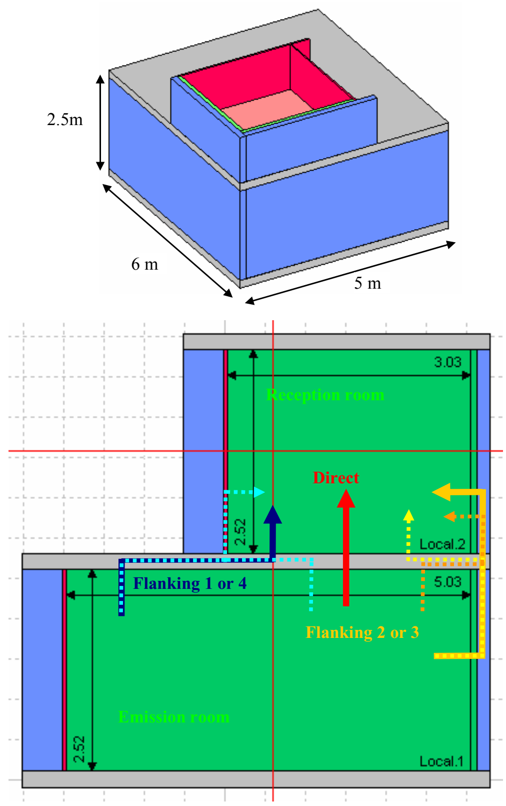


Fig.2 (a) Building configuration and (b) acoustic flanking paths.

For the 200 mm thick base floor, the type of thermal floating floor has little influence on the obtained acoustic insulation D_{nTA}. Fig.3 presents the detail of the different transmission path (direct and flanking paths) when the thermal floating is used on a 200 mm base floor and that façade thermal lining is implemented in the reception room (dwelling) only. It can be seen that if the façade thermal lining ESA3 is used, all the transmission paths, direct and flanking, contribute to the sound transmission. When the façade thermal lining ESA5 is used, the direct and flanking path 1 and 4 (as identified in Fig. 2) are associated to the sound transmission. Table 3 presents the obtained results. French regulation can only be fulfilled between a garage and a kitchen or bathroom if the most performing thermal lining ESA5 is used on the complete building façade (respecting the required D_{nTA} of 52 dB with the 1 dB margin).

In order to achieve the requirement it was decided to first consider an increase of the base floor thickness from 200 to 230 mm. The improvement in the acoustic insulation D_{nTA} is in the order of 1 to 2 dB (see Table 3). However, the required performance D_{nTA} of 55 dB can be reached without a margin with the ESA5 lining on the complete façade (see Table 3). The solution of including a thin acoustic resilient layer as a complement to the thermal insulation layer in order to achieve the acoustic requirements was investigated and is presented in the next section.

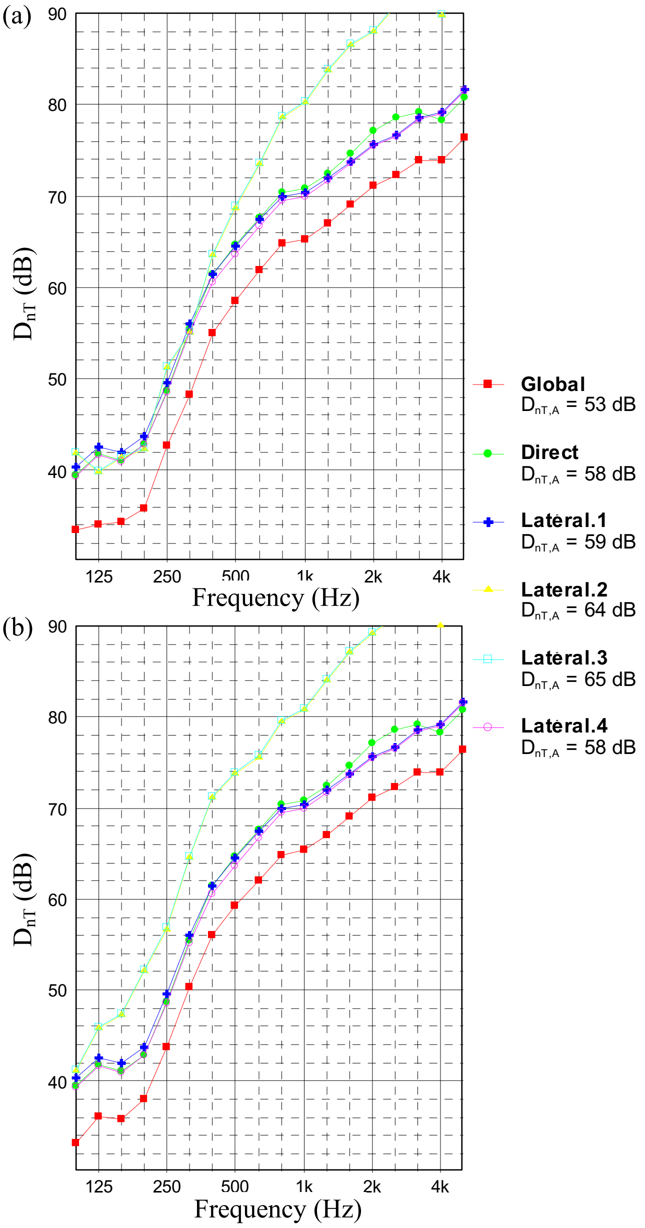


Fig.3 Building acoustic performance with thermal floating floor on 200 mm base floor; with (a) ESA3 and (b) ESA5 thermal lining in reception room.

Thermal lining	Thermal floating floor	
	200 mm	230 mm
ESA3 – Emission+reception	50	51
ESA3 –Reception	51	53
ESA5 – Emission+reception	53	55
ESA5 –Reception	53	54

Table 3 Acoustic insulation D_{nTA} for 200 or 230 mm base floor, 60 mm floating slab and thermal insulation layer.

4 Thermo-acoustic floating floors

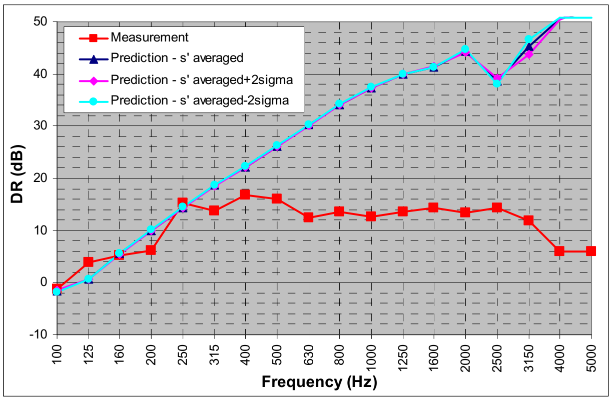
The prediction model was first used to evaluate the performance of a thermo-acoustic combined layer solution. A thin acoustic resilient layer composed of a glass fibber layer and a bituminous film (3 mm in total thickness) was chosen since it is a layer commonly used for floating system. The thickness of the global floating system is therefore not much modified. After validating the approach with a combine thermo-acoustic layer, some measurements were carried out to corroborate the predicted results.

4.1 Performance on 200 mm base floor

Thermo-acoustic floating floor systems combining a 200 mm thick concrete base floor, a thermal insulation layer as well as a thin acoustic resilient layer and a 60 mm thick floating concrete layer are then considered in this section. The results in terms of acoustic performance ΔR and ΔL are presented in Fig.4 for the expanded polystyrene layer.

As observed previously, above 250 Hz, the measured performance ΔR remains limited around 10-12 dB; this limitation is related to a transmission path that is not taken into account in the model. The acoustic performance with respect to impact noise ΔL predicted by the model is close to the measured one up to 1250 Hz.

(a)



(b)

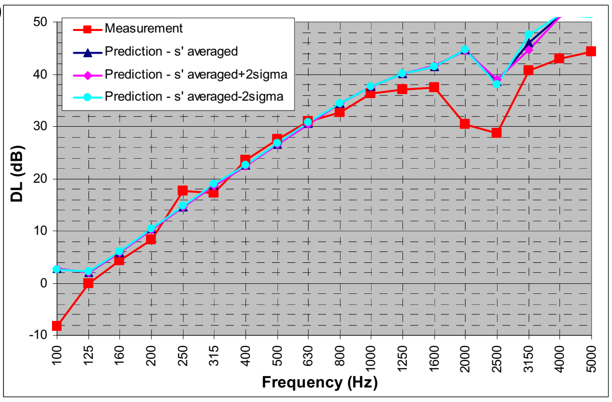


Fig.4 Acoustic performance of thermo-acoustic floating floor; (a) airborne noise and (b) impact noise.

Table 3 presents the corresponding global acoustic index. As expected, by introducing a thin acoustic resilient layer, the acoustic performance is well improved; the performance with respect to airborne noise Δ(Rw+C) is increased by 6 dB. The predicted performance with respect to impact noise Δ(Lw) is increased by 8 dB while the measured one by 2 dB only; this difference between the measurement and the prediction arise from the difference observed in Fig.4 for the third octave band 100 Hz.

Similar results were obtained for the thermo-acoustic floating floors with the others types of thermal layers considered. In general, the predicted performance is close the measured one. The acoustic performance obtained with the thermo-acoustic system is close to the one achieved with the thin acoustic resilient layer only.

Base floor 200 mm – Floating concrete floor 60 mm	Δ(Rw+C) dB	Δ(Lw) dB
Measurement	8	22
Prediction – s' average	6	24
Prediction – s' average+2σ	6	24
Prediction – s' average-2σ	6	24

Table 3 Global acoustic index for thermo-acoustic floating floor.

Predictions were again carried out for a base floor thickness of 230 mm. The acoustic performance with respect to airborne and to impact noise is only slightly modified in the low frequency range when the base floor thickness is increased from 200 to 230 mm; the global acoustic indexes are decreased again by 1 dB.

4.2 Building performance

Building acoustic performance has to be predicted to validate the thermo-acoustic floating floor implementation with respect to the French acoustic regulation. The building described in Section 3.3 and Fig. 2 is again considered. Measured performance on the 200 mm thick base floor thermo-acoustic is used for the building performance predictions. The effect of a third thermal insulation lining, denoted ESA4, with an intermediary performance $\Delta(R_w+C)$ of 3 dB, is also considered to be applied on the façade.

Table 4 presents the obtained acoustic insulation D_{nTA}. The use of the thermo-acoustic floating floor between a garage or store and an apartment allows having different solutions to fulfil the French regulation. The different requirements (from the lowest 52 dB to the highest 58 dB) can be reached with the thermo-acoustic floating floor. The façade thermal lining can be selected to attain the desired requirement. Furthermore, it is not necessary to implement a 230 mm base floor to reach the requirements.

Thermal lining	Thermal floating floor	
	200 mm	230 mm
ESA3 – Emission+reception	52	53
ESA3 –Reception	55	56
ESA5 – Emission+reception	59	60
ESA5 –Reception	58	59
ESA4 – Emission+reception	55	56
ESA4 –Reception	57	58

Table 4 Acoustic insulation D_{nTA} for 200 or 230 mm base floor, 60 mm floating slab and thermo-acoustic insulation layer.

5 Parametric study

Part of this project was also concerned with the pertinence a mixed approach combining measurements and numerical predictions. Indeed, since laboratory measurements concerning floating floors are usually performed on a 140 mm thick concrete base floor with a 40 mm thick floating slab, it would a great interest to extend measured results by prediction of the acoustic performance of different combinations: different thicknesses of the base floor, of the floating slab or of the resilient layer. To this end, the thermal floating floor based on the expanded polystyrene was also experimentally tested on a 140 mm thick based floor with two different thicknesses of floating slab (40 and 60 mm). Measurements were also carried out on the 140 mm base floor with the 40 mm floating slab with a different thickness of the thermal insulation layer (30 mm instead of 72 mm). Table 5 presents the global acoustic indexes obtained from the measurements and from the predictions. In the left column, the first number represents the base floor thickness, the second the thermal insulation layer thickness and the third the floating slab thickness.

Floating System	Measurement	Prediction
$\Delta(R_w$+C) in dB		
200 – 72 – 60	2	0
140 – 72 – 60	4	3
140 – 72 – 40	1	1
140 – 30 – 40	-1	2
$\Delta(L_w)$ in dB		
200 – 72 – 60	20	16
140 – 72 – 60	19	19
140 – 72 – 40	18	16
140 – 30 – 40	18	17
ΔL_w in dB		
200 – 72 – 60	–	–
140 – 72 – 60	17	18
140 – 72 – 40	17	16
140 – 30 – 40	16	17

Table 5 Global acoustic index for different thermal floating floors considered in parametric study.

First, it should be mentioned that the elastic modulus of the thermal layer deduced from the dynamic stiffness measurement (see Section 2) was quite different (factor of 2) for the two different thicknesses considered. This might be the reason why the variation in performance associated to the variation in thermal layer thickness obtained from the predictions is opposite to the one obtained from the measurements. However, in general, it can be noted in Table 5 that the variation in performance with respect to airborne noise obtained from the prediction model is rather conservative compared to those obtained from the measurements. This is not the case for the variation in performance with respect to impact noise: the variations obtained from the prediction are quite different and even opposite to those obtained from the measurements. However, the prediction model is able to evaluate relatively well the variations of the acoustic performance in the low frequency range associated to the thickness variation of the base floor and the floating slab (indeed the variation of the minimum in acoustic performance with respect to frequency is well predicted compared to the measurements).

6 Conclusion

This project has demonstrated that it is possible to develop a thermo-acoustic floating system in order to fulfil both the thermal and the acoustic French regulation between garage or store and a dwelling. These thermo-acoustic floating systems combine a thermal insulation layer and a thin acoustic resilient layer, and a 60 mm floating slab. A base floor 200 or 230 mm in thickness can be implemented. On the base of the parametric study conducted by measurements and predictions, it appears that the model could be used to extend measured results on the standard 140 mm base floor with a 40 mm floating slab, to other configurations for airborne noise excitation. The validation of the model with respect to impact noise is limited. Other floating systems should be investigated to further evaluate the approach.

Acknowledgments

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