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B. Liengaard, Julie; F. Gotfredsen, Melanie; Rasmussen, Birgit; Bolberg, Mads; Jeong, Cheol-Ho; Brunskog, Jonas

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IMPROVING THE SOUND INSULATION OF EXISTING WOODEN FLOOR CONSTRUCTIONS – EXPERIENCES FROM A LABORATORY STUDY

Julie B. Liengaard[1] **Melanie F. Gotfredsen**[1] **Birgit Rasmussen**[2]
Mads Bolberg[3] **Cheol-Ho Jeong**[1] **Jonas Brunskog**[1]*
[1] Acoustic Technology, DTU Electro, Technical University of Denmark, Denmark
[2] BUILD, Aalborg University Copenhagen, Denmark
[3] ROCKWOOL A/S, Denmark

ABSTRACT

Many Danes live in older apartment buildings with wooden floor constructions with timber joists. Common for these is that the sound insulation is poor. However, these floors often have a regular design, which indicates that a good improvement strategy would work for many apartments. Moreover, the simple wooden flooring makes it possible to dissemble down to the load-bearing beams. In this paper we report experimental laboratory work investigating how to improve the sound insulation of such wooden floors by renovation. The goal is to improve the sound insulation to fulfill the Danish building regulations, considering both airborne and impact sound insulation. The main test specimen is a replica of the traditional wooden floor, built in 1998 in connection to another project. A few different floor renovations have been chosen for this laboratory study and the floor construction has been made both with and without an added acoustic ceiling. Comparisons are made to the results in the previous projects.

Keywords: *Sound insulation, Timber construction, Renovation, Impact sound*

**Corresponding author*: *jbru@dtu.dk.*

1. INTRODUCTION

Many Danes has their everyday life in an apartment with a timber joist floor construction, built before 1959 [1]. These buildings are associated with beautiful and detailed facades and interior, giving them a large conservation value. However, nowadays we also have a greater focus and knowledge about the indoor environment and comfort in our homes. The homes in most multi-storey buildings built before 1959 do not comply with today's demands on sound insulation. There exist around 500.000 such apartments in Denmark [2–4].

This paper seeks to investigate, through experimental work in the lab, how to improve the sound insulation between dwellings through renovation by insulation of the wooden floor construction. Laboratory measurements have been performed on a wooden construction used in previous projects [5, 6]. This construction is a replica of the construction built with the building techniques of the aforementioned time period. Both airborne sound insulation and impact sound insulation are studied. A number of modifications of the original construction will be tested in order to improve the sound insulation and at the same time having a reasonably simple construction. The constructions have been tested in laboratory. The work is based on two student reports [7, 8] and some results have been reported before [9] (using some of the same constructions, but measured independently).

2. METHODS

2.1 Measurements

The measurements were done in the transmission rooms at DTU, following the ISO 10140 standards [10, 11], with some exceptions. The upper room has a volume of 240 m^3 and the lower room volume is 245 m^3. Sealing the edges for leakage was done by adding mineral wool and duct tape at the edges. The test specimens were loaded with an additional 25 kg per square meter. The first airborne sound insulation measurements were carried out from "up to down" with the source room as the upper room and the receiver room in the basement. These measurements were done with a B&K 2250 sound level meter in 6 positions for each room fixed for all measurements, and using 2 fixed loudspeakers placed in corners. Impact sound were measured with a B&K 3204 tapping machine in 5 fixed positions. Additional measurements with the soft/heavy ball were also performed, but not shown here (see [9] for more on this subject). For the second round of investigations airborne sound insulation measurements were made from "down to up" using in-room omnidirectional loudspeakers and rotating microphone booms. For the impact sound measurements a B&K 3204 tapping machine was used in 6 positions. For these second round measurements the Nor850 measuring system was used.

2.2 Constructions

In total, 10 different constructions were considered, see Fig. 1. In the first round of measurements 9 different constructions were investigated, including the original construction C0. For the second round of measurements only one construction was investigated, C5. The tested constructions are described in Table 1 to 6.

In each of Table 1-6, the constructions are divided in three parts. The top part consists of the materials above the wooden beams. The center part consists of the wooden beams and the materials in the cavity between the beams. The bottom part consists of the materials below the wooden beams. Constructions 1 to 4 come in two versions; one with the original bottom part construction denoted C1 to C4, and one with a resiliently suspended ceiling added to the original construction denoted C1C to C4C. Note that in Figure 1 the resiliently suspended ceiling is only shown for C1C, third from the top. Construction C5 is an extra construction added afterwards in order to investigate a few ideas and some learning from the first project. This construction only comes with the original

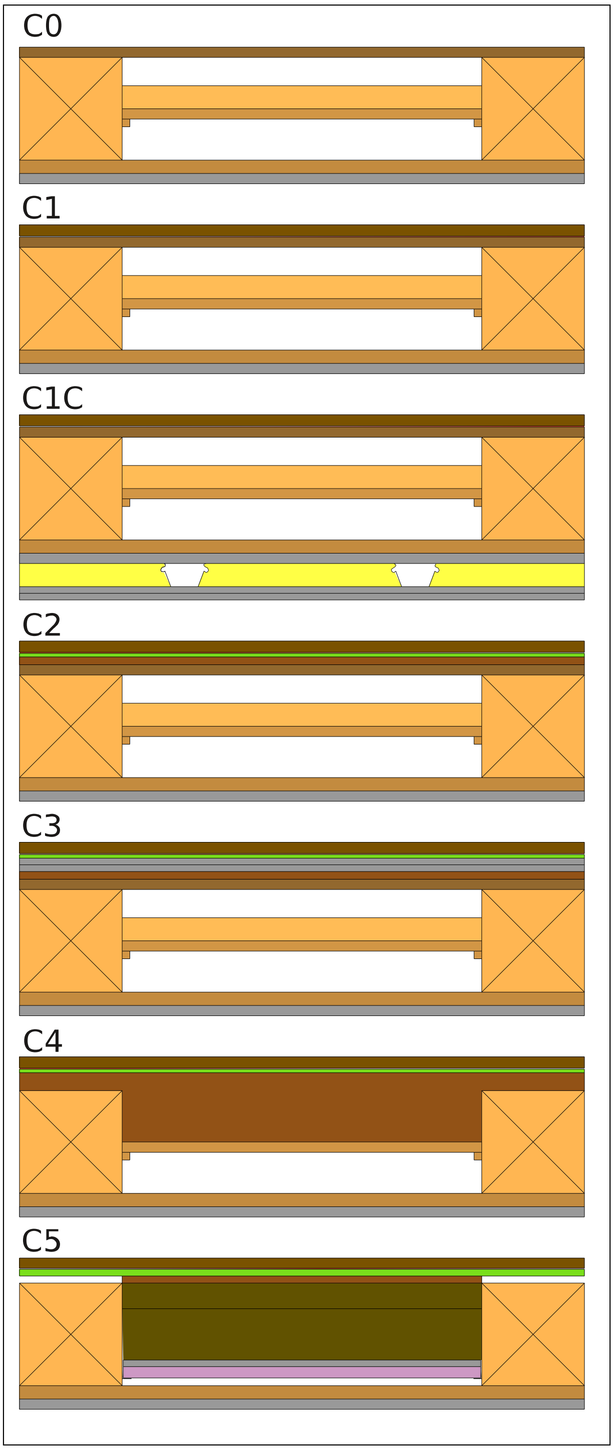

Figure 1. The constructions; 7 of the 10 constructions are shown. The remaining 3, C2C, C3C and C4C, have the same bottom as C1C.

bottom construction. In Tables 2 to 6 references are made back to previous constructions when a part is the same, in order to save space in the tables.

Construction C0, Table 1, is representing the original construction. For the center, the load bearing part of the construction consists of wooden beams 200 mm × 200 mm, separated center-to-center (cc) 900 mm. In between these are two air cavities separated by a layer of sand (representing the clay in the real constructions) supported by a 'blind floor' of 20 mm wooden planks. The top construction is a 28 mm wooden floor and the bottom is plaster on sarking boards.

Construction C1, Table 2, keeps the center and bottom from C0, but in the top is added a parquet floor on a resilient foam on top of the original wooden floor. C1C changes the bottom to a suspended ceiling, consisting of resilient 'sound clips' from Knauf (mounted cc 450 mm) and a layer of two 13 mm gypsum boards. In the 45 mm cavity formed by the 'sound clips' is used lightweight stone wool, ROCKWOOL Flexibatts 37, with a norminal density 32 kg/m^3, denoted 'RW Flexibatss' henceforth [12]. The suspended ceiling is mounted to the C0 bottom construction.

Construction C2, Table 3, again keeps the center and bottom from C0 and on top of the original wooden floor is added a parquet floor (Junkers Industrier A/S) and foam (as C1) on 7 mm plywood board and a stone wool ROCKWOOL Trinlydsbatts for impact sound reduction with a nominal density 135 kg/m^3, denoted "RW Trinlydsbatts" henceforth [12]. The center and bottom is kept as in C0, and C2C is using the same suspended ceiling as C1C.

In construction C3, Table 4, again only the top construction is modified. It consists of a parquet floor, foam, plywood board, two layers of gypsum boards, and a stone wool 'impact sound mat' on top of the original wooden floor. For C3 the center and bottom is kept as in C0, and C3C is using the same suspended ceiling as C1C.

In construction C4, Table 5, modifications are done also in the center part of the construction. In the top, the original wooden floor is removed. The rest of the top is the same as in C2: parquet floor, foam, plywood board and stone wool 'impact sound mat'. In the center, the sand is removed and replaced with stone wool 'impact sound mat'. The 'blind floor' of wooden planks and the air cavity below it is kept from C0. For C4 the bottom is kept as in C0, and C4C is using the same suspended ceiling as C1C.

Construction C5, Table 6, is an additional test, measured after the first series of measurements. It has similarities with C4, as the original wooden floor is removed,

Table 1. Floor constructions C0, the original construction. The sand layer simulates as far as possible a layer of clay found in the real constructions.

Part	Material	Thickness
Top	Wooden floor	28 mm
Center	Wooden beams[1] &:	200 mm
	Air	45 mm
	Sand	45 mm
	Blind floor[2]	20 mm
	Air	90 mm
Bottom	Sarking board[2]	26 mm
	Plaster	20 mm
1	W 200 mm,	cc 900 mm
2	Wood	

Table 2. Floor constructions C1 and C1C.

Part	Material	Thickness
Top	Parquet floor	20 mm
	Foam	2 mm
	Wooden floor	28 mm
Center	As C0, Table 1	
Bottom C1	As C0, Table 1	
Bottom C1C	Sarking board[1]	26 mm
	Plaster	20 mm
	RW Flexibatts[2]	45 mm
	Gypsum board	2 × 13 mm
1	Wood	
2	& Sound clips,	cc 450 mm

Table 3. Floor constructions C2 and C2C.

Part	Material	Thickness
Top	Parquet floor	20 mm
	Foam	2 mm
	Plywood board	7 mm
	RW Trinlydsbatts	15 mm
	Wooden floor	28 mm
Center	As C0, Table 1	
Bottom C2	As C0, Table 1	
Bottom C2C	As C1C, Table 2	

Table 4. Floor constructions C3 and C3C.

Part	Material	Thickness
Top	Parquet floor	20 mm
	Foam	2 mm
	Plywood board	7 mm
	Gypsum boards	2×13 mm
	RW Trinlydsbatts	15 mm
	Wooden floor	28 mm
Center	As C0, Table 1	
Bottom C3	As C0, Table 1	
Bottom C3C	As C1C, Table 2	

Table 5. Floor constructions C4 and C4C.

Part	Material	Thickness
Top	Parquet floor	20 mm
	Foam	2 mm
	Plywood board	7 mm
	RW Trinlydsbatts	15 mm
Center	Wooden beams[1] &:	200 mm
	RW Trinlydsbatts[2]	90 mm
	Blind floor[3]	20 mm
	Air	79 mm
Bottom C4	As C0, Table 1	
Bottom C4C	As C1C, Table 2	
1	W 200 mm,	cc 900 mm
2	H 6 x 15 mm	
3	Wood	

and the center part is modified. The top part is thus the same as C4, with the exception that there here is an air gap between the wooden floor and the load bearing wooden joists, see Figure 1, the last construction. The purpose was to reduce the mechanical connection between the top construction and the wooden joists. The difference is in the center part where instead of using RW Trinlydsbatts only, most of it is made up by ROCKWOOL Toprock Terrance Lamel with nominal density of 140 kg/m^3, denoted 'RW Toprock' henceforth [12]. This stone wool product has about three times higher dynamic stiffness, s_t, than the RW Trinlydsbatts, that is around 65 MN/m^3 [8]. This ensures that the floor is not "bouncy" to walk on, which was the experience with the C4 floor. The 'blind floor' is here made of 28 mm OSB particle board and an extra 13 mm gypsum board is added to it. The 'blind floor is mounted with steel brackets. The air cavity below the 'blind floor' is reduced in size. The bottom is kept as in C0, and no

Table 6. Floor construction C5.

Part	Material	Thickness
Top	Parquet floor	20 mm
	Foam	2 mm
	Plywood board	13 mm
	RW Trinlydsbatts	15 mm
Center	Wooden beams[1] &:	200 mm
	RW Toprock[2]	150 mm
	Gypsym board	13 mm
	Blind floor[3]	28 mm
	Air	$<$ 10 mm
Bottom C5	As C0, Table 1	
1	W 200 mm,	cc 900 mm
2	H 100 + 50 mm,	
	W 200 mm, L 1 m	
3	OSB particle board	

version with suspended ceiling was tested.

3. RESULTS AND ANALYSIS

The single value ratings for airborne sound insulation is shown in Table 7; the ones used in Danish regulations [13] and classification standard [14] are used, as found in ISO 717 [15], R_w, $R_w+C_{50-3150}$ and R_w+C_{tr} (note however that in the regulations it is the field values being used, not the laboratory values as reported here).

Figure 2 is showing the sound reduction R for the nine constructions. We can see that the results arrange itself in three groups: C0 is worst, constructions C1 to C5 are in the middle and constructions C1C to C4C are the best.

Table 7. The single value ratings for airborne sound insulation in dB.

Constr.	R_w	$R_w + C_{50-3150}$	$R_w + C_{tr}$
C0	53	50	45
C1	58	54	51
C2	59	55	52
C3	60	56	52
C4	59	55	52
C5	56	53	49
C1C	62	58	54
C2C	63	59	56
C3C	63	59	56
C4C	63	57	56

The single value ratings for impact sound insulation are found in Table 8, showing $L_{n,w}$ and $L_{n,w} + C_{I,50-2500}$. Finally, Figure 3 is showing the impact sound level L_n for the nine constructions. Also here C0 is worst and the constructions C1C to C4C, with the resiliently suspended ceiling, are the best. However, as compared to airborne sound insulation, the spread in the results are larger; e.g., C1 is clearly worse than the other constructions without the suspended ceiling.

Table 8. The single value ratings for impact sound insulation in dB.

Constr.	$L_{n,w}$	$L_{n,w} + C_{I,50-2500}$
C0	62	63
C1	60	61
C2	58	59
C3	56	57
C4	55	57
C5	57	59
C1C	52	57
C2C	51	58
C3C	49	56
C4C	49	56

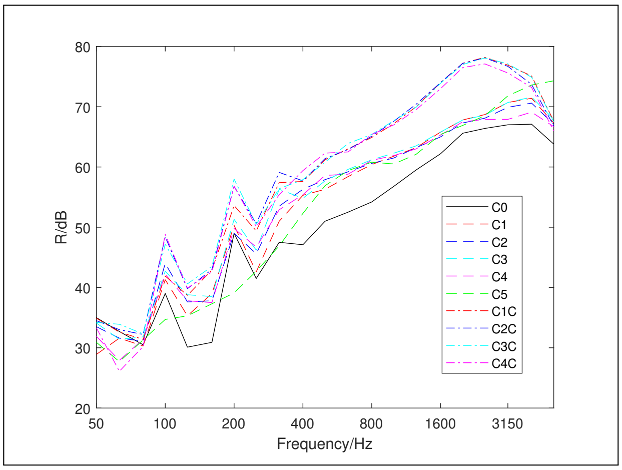

Figure 2. Sound reduction R for the 10 constructions.

4. DISCUSSION

We believe there have been some problems with the first set of measurements, constructions C0-C4 and C1C-C4C. There are two problems: First, in Figure 2, at the highest frequencies the R is turning downward. This is most likely explained with a remaining problem of leakage. For construction C5, this effect is much smaller, and the leakage sealing probably worked better here. Second, in the low frequencies there are two peaks in R at 100 Hz and at 200 Hz. We believe this has to do with problems either with the deployment of the loudspeaker or microphone. 6 fixed positions were used for the microphone, and two corner positions were used for the loudspeaker. For C5 a much smoother curve is seen in the low frequencies, as would be expected. For C5, a rotating microphone was used as well as omni-directional loudspeakers in the room. Also, the second measurement, C5, was done 'down to up', which also might play a role. Despite these problems, comparison between constructions C0-C4 and C1C-C4C should be without much problem, and the single value ratings are probably not affected very much. But when com-

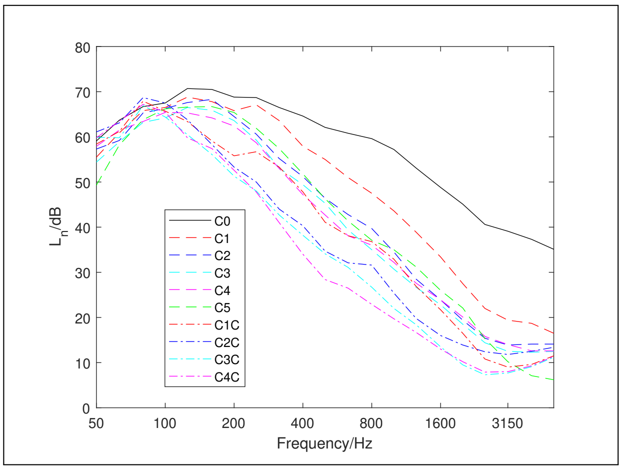

Figure 3. Impact sound level L_n for the 10 constructions.

paring the first set of measurements with C5, especially at low and high frequencies, we need to be careful.

In [9] independent measurements were done for some of the constructions. The low frequency problems were not seen in these measurements, confirming our doubts regarding our measurements.

Keeping these limitations in mind, one conclusion we can draw from these measurements, anyway, is that the resiliently suspended ceiling gives the largest effect, both for airborne sound and for impact sound. For airborne sound, Figure 2, R is clearly grouping in three categories above ca. 250 Hz: C0 is worst, C1 to C5 is in an in-between group, and C1C to C4C is the best group. Within these groups the results are very similar.

As the different top constructions give so similar results, a reasonable strategy is to select the simplest of them as the recommended one. Simplicity here partly means the complexity of the construction, and partly the construction height for the top construction. Keeping this height low simplifies other practical aspects.

To comply with the current day Danish building regulations [13] $R'_w \geq 55$ dB and $L'_{n,w} \leq 53$ dB must be fulfilled, corresponding to class C in the classification standard DS 490:2018 [14]. As these values apply to in-situ measurements only, which includes flanking transmissions, we cannot directly apply them to our results. However, if we assume a safety margin of 3 dB, C2-C4 and C1C-C4C would be able to provide acceptable airborne sound insulation, but only C3C and C4C could give acceptable impact sound insulation. As both criteria needs to be fulfilled only these two meet the requirement, but one should keep in mind that the flanking transmission could lead to non-compliance, since a suspended resilient ceiling would have less effect on this transmission. Of these two, C3C have the benefit that the original construction is kept, and the modifications are only in the top, above the original floor, and in the bottom, below the original floor. On the other hand, C4C has the benefit that of a lower construction height, especially in the top construction. A significant increase of the floor height can be a problem in renovations, since this can lead to necessary changes for doors and stairs.

Moreover, the most complex constructions in this project are also C3C and C4C. C3C has a lot of different material layers, even considering that the many layers of RW Trinlydsbatts could be replaced by few and thicker slabs, the C4C would still require a lot of cutting work with varying measures. Also, the C4C (and C4) construction has the practical worry of whether it can withstand static load. The absence of the original plank floor causes the blind floor to carry loads and as the blind floor is not designed for this, C4C requires project specific evaluations of the building statics for every project. We should note that during the test, the C4 and C4C constructions were experienced as unpleasantly bouncy to walk on. This was the motivation for the C5 version, which show performance close to the C2. This leads to the expectation, that a C5C probably would perform like C2C and therefore would be just outside the desired range.

It is worth noting that the current performance of the C0 floor is expected to correspond to the the Class E of the Danish classification standard DS 490:2018 [14], again not considering flanking transmission. The standard predicts that a Class E corresponds to that only 10-25% of the public would deem sound environment good or very good, whereas 45-60% will find it bad. With only a small improvement, the floor have a good chance to reach Class D. This would correspond to 30-45% finding the sound environment good or very good and the part finding it bad would be 25-40%. From this perspective also simple and smaller improvement should be considered, since it still has a great impact for a significant part of the public.

5. CONCLUSIONS

The airborne and impact sound insulation of one replica of a traditional wooden floor construction, and 9 modifications to this construction have been measured in the laboratory.

We can conclude that for these constructions, the largest effect comes by adding the resiliently suspended ceiling, especially for airborne sound insulation. For impact sound insulation, also the top construction are important.

As only laboratory measurements have been done, we can not draw strong conclusions if these constructions can be used in field, fulfilling the building regulations in Denmark. If however assuming a margin of 3 dB, two of the constrictions do fulfills the building regulations. However, these two constructions are also the two most complex constructions.

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