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# Classification and effect of floor treatment on wood frame construction

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**Several recent NRC studies have investigated the change of sound insulation of lightweight framed floors, due to the addition of floor treatments (toppings and coverings). In this paper, a method to classify floor treatments as globally reacting or locally reacting is presented. A floor treatment that is locally reacting affects only the injected power and not the propagation of structure-borne sound to and through a junction. In this case, the floor treatment affects direct and all flanking sound transmission paths the same, for all path directions. A globally reacting floor treatment affects sound transmission in different paths differently, since it alters both the power injected, and the path itself. In this study lightweight wood frame floors were considered, where for globally reacting floor treatments, orientation of the floor treatment relative to the joists orientation are important parameters for their effectiveness. Several floor treatments (two toppings and six coverings) were measured and classified as locally or globally reacting, and effects are compared. Most of the floor treatments improved sound insulation, but two worsened it.**

## 1 INTRODUCTION

In lightweight wood framed construction (WFC) the dominant flanking paths for both airborne and impact sources between horizontally and vertically adjacent rooms typically involve the floor surface [(1)], and some form of treatment – a floor topping – is required to ensure sufficient sound insulation quality.

In WFC, floor joists are always oriented perpendicular to load bearing junctions and parallel to non-load bearing junctions. Flanking sound insulation usually is different for both directions and thus two sets of flanking path data are necessary to fully characterize an assembly. Furthermore, the effect of a floor treatment may also be different for direct transmission through the floor-ceiling assembly, and for flanking in both directions, so overall goal of this study is to be able to predict the effect on all. In the future the effect on direct sound transmission could possibly be

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predicted using the system properties of the floor and of the floor treatment, from which the effect on flanking sound transmission could further be predicted.

To better understand how floor treatments influence the sound insulation, this paper (in an initial step toward the overall goal) attempts to classify floor treatments as globally or locally reacting floor treatments, depending on how they affect sound transmission in different sound transmission directions. Floor treatments that affect all directions similarly are classified as locally reacting whereas treatments that affect paths differently are classified as globally reacting. However, clear criteria do not exist.

Note that this paper focuses less on absolute levels of impact and airborne sound insulation, but more on the change due to floor treatments in WFC. After explanation of which and how path insulation data was determined and how floor treatments could be classified, the actual effects of the floor treatments are discussed.

The paths affected by floor treatments are illustrated in Fig 1. For the case of rooms one above the other, there is the direct floor-ceiling path (black arrow) and the two floor-wall paths (green arrow). For the case of rooms side-by-side, there is the floor-floor path (blue arrow) and the two floor-wall paths (red arrow).

## 2 FACILITY AND SPECIMEN

### 2.1 NRC Flanking Facility

Impact and airborne sound transmission tests for this study were conducted in the NRC Flanking Facility (see Fig. 2 and (2) for a more detailed description) that has eight rooms (four upstairs and four downstairs). The specimen consists of eight walls, four floors, and six junctions, as the decoupled rigid outer shell belongs to the facility. On a single specimen, the evaluation can be made of the flanking transmission across a wall-wall junction as well as across load bearing and non-load bearing wall-floor junctions.

### 2.2 Specimen

Two toppings and six coverings were evaluated on a wood I-joist floor supported by single 2x4 wood stud walls (described in Table 1 below). All eight specimen walls were identical, and all four specimen floors were also identical.

At the load bearing floor-wall junction, the floor joists were discontinuous. They rested on the wall at one side, and were attached via joist hangers to a rim-board on the other side. A load, simulating a typical ½ storey load, was applied to the upper load bearing wall. Previous research showed that flanking sound transmission changed initially when some loads were applied but remained constant if load is further increased above the equivalent of ½ storey (3).

The floor treatments tested for airborne and impact sound transmission and more detailed descriptions are in Tables 2 and 3 below. As carpet and vinyl were already proven in a previous study (4) to give the same improvement for impact sound insulation whether covering the full floor or the partial floor (patch), and to have an insignificant effect on airborne sound insulation compared to a bare floor, for some tests only a patch of carpet or vinyl was used.

## 3 MEASUREMENT PROCEDURE AND LIMITATIONS

### 3.1 Measurement procedure

Testing was done in accordance with ISO 10848 to capture sound insulation of paths of interest (shown in Fig 1) for airborne and the light impact (ISO tapping machine) source. Shielding by placing acoustical insulation and heavy gypsum board panels in front of a wall to suppress transmission through it, was applied to the specimen to ensure that only the paths of interest were being measured as described in [5] in more detail. Table 4 shows the paths with corresponding shielding conditions.

Note that an alternate path was measured instead of the vertical floor-wall path in order to simplify the measurement method, namely, the diagonal floor-wall path (purple arrow in Fig. 3 left), as in a previous study [6] both were shown to be equivalent. Structure borne sound that reaches the studs of the wall below through a symmetrical floor-wall junction, excites the gypsum board on both sides of the wall the same, causing similar vibration and radiation, finally resulting in equivalent sound transmission.

To characterize the effect of the floor treatment, comparisons were made between the airborne and light impact measurements made on a reference floor and the same floor after the floor treatment was applied. Reference floors could be the bare floor (9A) or the floor with toppings (9C and 9D).

### 3.2 Measurement limitations

An example of measurement limitations are shown on the impact sound transmission paths depicted in Fig. 4, for carpet covering the bare reference floor (case 9A-C).

As expected [1] direct transmission has the highest levels followed by the horizontal and finally diagonal flanking transmission. With the carpet installed it is difficult to identify if the load bearing or non-load bearing path is dominant, as they are both attenuated so strongly by the carpet. Commonly, the load bearing direction (along the joists) is worse, as more sound gets transmitted via the joists, than the non-load bearing direction (parallel to joists), where sound is attenuated efficiently across the joists.

In the high frequency range the influence of background noise becomes apparent. For some very effective airborne sound treatments (e.g. wood raft in source and receive room) flanking sound transmission (through the facility walls) limits the results.

In the low frequency range, below 100 Hz some airborne data is influenced by background noise, due to limited source levels (loudspeaker limitations), and some impact data is influence by "indirect noise", which for the vertical floor-ceiling path (direct) is noise generated by the tapping machine in the source room and transmitted to the lower room via airborne paths (see sketches in Fig. 5). For the diagonal floor-wall path, sound generated in room below the source room is transmitted to the diagonal room as indirect noise as shown in Fig. 6.

The indirect noise was, for the vertical (left) case, calculated by subtracting the level differences from airborne tests from measured impact sound levels in the source room. For the diagonal (right) case, the indirect noise was calculated by subtracting the level difference of the lower wall measured in a sound transmission loss test from the measured noise in the room below the source. This is most important for the low frequency range, where the sound insulation of a double leaf wall is not very high.

Notice that in the very low frequency range the indirect sound is even larger than the direct sound, which is not physical. This falsification could be due to room mode coupling or the different excitation (impact hammer quasi stationary, location on floor only versus airborne excitation with pink noise from four independent sources) or simply due to the large measurement uncertainty in this range. Therefore, results were not corrected, although possibly contaminated by indirect noise below 100 Hz.

Further, the influence on the change due to a floor treatment is assumed to be small for cases where the floor treatment changes the direct sound the same as the indirect, as probably is the case on the diagonal.

## 4 RESULTS

In this section the floor treatments will be classified and their effect on impact and airborne sound insulation will be described.

### 4.1 Classification

As previously briefly mentioned, the classification of floor treatments will be made by comparing the change of the sound insulation in the five directions listed in Table 4. To illustrate this, the effectiveness of floor coverings for impact noise is show in Fig. 7 for two extremely different examples, namely, carpet (9A-C) and strip wood flooring (9A-S1) installed with the long axis perpendicular to the joists.

The carpet has a large improvement on the bare floor, with a slope of approximately 10 dB per octave, reaching a improvement of over 30 dB at 1k Hz, where background noise starts to effect results. The carpet seems to influence all five directions very similarly.

The strip wood flooring (S1) on the other hand, has different improvements for the different directions, whereby the non-load bearing cases (diag_nlb and hor_nlb) and load-bearing cases (diag_lb and hor_lb) follow the same trends. In the low frequency range the improvement (positive number) is very small, whereas above 500 Hz the sound insulation is worsened, which is more pronounced for the non-load bearing case than for the load bearing case. Structure-borne sound travelling along the length of the strip wood flooring, which is oriented perpendicular to the joists, is less attenuated due to fewer joints and the greater stiffness in this direction, so more sound energy is transmitted towards the load bearing junction.

As for most cases the largest directional difference in the effect of floor treatment could be seen between the load bearing and non-load bearing directions, these two were used to establish classification criteria. The difference of improvement to the direct transmission was not considered in this analysis, because they were small for most cases and either very close to one direction or in between both.

To reduce the data sets the load bearing horizontal and diagonal effects and the non-load bearing horizontal and diagonal effects were averaged as they were seen to be very similar. The difference between the averaged load and non-load bearing changes are sorted in three classification groups in Fig. 8. For classification purposes light impact instead of airborne data was used, because differences between the two directions are more pronounced. Impact noise propagates from the impact source (near the middle of the room) through the floor and hence is more affected by a globally reacting treatment than airborne noise that excites the floor also close to the junction which contributes most to the transmitted sound as shown in previous studies [7]. The similarity of the horizontal and diagonal change in one direction indicates the floor treatment does not affect junction attenuation.

The vinyl and carpet, as expected, showed the least difference between the directions (less than 3 dB), for patches and with the full floor covered as on the wood-raft topping (9C) and is considered locally reacting. To the other extreme, the biggest difference between the two directions of up to 10 dB (less than 5 dB for airborne source) was observed for the strip wood flooring oriented with the long axis perpendicular to the joists and is considered globally reacting. A classification of the other six floor treatments in middle (engineered, laminate, ceramic, strip wood parallel joists, wood raft, and OSB overlay) as locally or globally reacting is not so straightforward, as the differences are only slightly bigger than the repeatability limits given in the ISO 140 standard. Incorporating other properties such as bending stiffness, mass per area, or mobility could possibly better support a clearer classification.

Note, the directional differences of the coverings were slightly smaller when applied on the reference toppings (9C and 9D).

## 4.2 Effect

Assuming the "middle" floor treatments are locally reacting and to simplify comparison of the effect of floor treatments, the average of all five directions will be examined instead of the single directions. For vertical sound transmission this makes sense even for the globally reacting floor treatment, as most commonly, with one room over the other, two junctions are load bearing and two are non-load bearing, leading to an average effect. The effect of all floor treatments can be found in Fig. 9 for light impact.

Some of the floor treatments act very similar, for example the laminate flooring (red) and engineered wood flooring (turquoise), both on a resilient mat with similar mass. Also trends for the vinyl and the OSB overlay are similar above 315 Hz which is probably a coincidence. Finally, the effect of the strip wood flooring installed in the two directions is similar averaged over the five directions and is actually the worst of the samples tested on the bare reference floor (9A). For the strip wood flooring the improvement as stated earlier becomes negative, due to being directly attached to the subfloor with staples, having no underlayment to decouple vibration form the floor, and mainly due to the hard surface causing more power to be injected in the high frequencies from the now better impedance match of source (hammers of tapping machine) and floor (strip wood). The vinyl and OSB overlay with a softer surface show the next best improvement, followed by the stiff wood raft installed on a resilient mat. The laminate and engineered wood flooring although being lighter than the wood raft improve more above 315 Hz, probably because of the large amount of joints that each cause attenuation. Also the wood raft is probably stiffer, causing larger wavelengths, meaning the junction is closer to the source relative to the wavelength and the waves are less attenuated by the time they reach the junction. In the low frequency range below 200 Hz on the other hand, as expected, the wood raft, due to its higher mass, has higher improvement. Finally, biggest improvement is achieved by the carpet. So unfortunate that carpet has come out of style.

Improvements similar to those of the impact source were found for airborne sound insulation tests with the stiffer floor treatments (unlike the carpet and vinyl), but usually slightly smaller, except for cases where the impedance match between impact hammers and floor treatment governed the results as for the strip wood flooring. Note, the strip wood flooring never worsens airborne sound insulation and is comparable to the OSB overlay, having only slightly more mass.

The effects of the coverings on the wood raft toppings are omitted in this paper as they compare well to those when installed on the bare floor, yet slightly less pronounced in both positive and negative direction.

The impact sound insulation results for three coverings installed on the OSB overlay including, ceramic tiles, are presented in Fig. 11. The engineered wood flooring performs similar as on the bare floor but the effects are less pronounced, also with an increasing improvement to approximately 630 Hz at which the improvement gradually falls. The strip wood flooring shows a negative improvement around 1k Hz, as on the bare floor. The ceramic tiles, only tested on this topping as bare floor and wood raft do not provide a sufficiently stiff base, have an approximately 3dB bigger improvement in the low frequency range than the strip wood flooring because of the ceramic tiles have almost the double mass. However, the improvement decreases

at a lower frequency (around 315 Hz) than for the strip wood flooring, due to the harder tile surface shifting the unbeneficial impedance match to lower frequencies.
The effects for airborne sound insulation of the coverings applied to the two toppings (not shown here) are also very similar to the effects seen on the bare floor, again slightly less pronounced. The ceramic tiles installed on the OSB overlay give an improvement of approximately 6 dB over the whole frequency range, whereas the strip wood flooring with half the mass shows the same trend with a 3 dB improvement.

## 5 SUMMARY AND CONCLUSIONS

A simplified measurement methodology was used to determine the effect of floor treatments in the NRC-Flanking Facility for airborne and impact sound by shielding the specimen appropriately to capture all relevant sound transmission paths involving the floor with just one measurement per floor treatment.
It was found that the floor treatments do not influence the junction attenuation significantly. This was derived from the fact that the effect of floor treatment on all sound transmission paths in the same direction, for example for the two load bearing paths (horizontal and diagonal) are very similar.
Therefore, in further analysis the two paths for the load bearing junction and the two for the non-load bearing were averaged. The difference of the averages for the impact source was used to find classification criteria. The impact source was used instead of the airborne source, because of the larger effect it showed. The direct paths were excluded, because they usually lay in between the other two effects.
Some floor treatments could more easily be classified than others, such as carpet and vinyl as locally reacting and strip wood flooring installed perpendicular to joists as globally reacting. However, the difference in the directions for engineered wood flooring, laminate flooring, ceramic tiles, strip wood flooring installed parallel to joists, wood raft, and OSB overlay, had moderate differences. Depending on the accuracy desired, they could either be described as locally or globally reacting.
Other measures (such as stiffness or impedance) might be needed to classify the "middle" group of floor treatments better.
The order of effectiveness on impact sound insulation above 100 Hz, averaged over all directions from highest to lowest is: carpet, laminate or engineered wood flooring on a resilient mat, wood raft topping, OSB overlay, vinyl, ceramic tiles and strip wood flooring. The strip wood flooring performs especially poorly in the non-load bearing direction when installed with the long axis perpendicular to the joists. Therefore caution should be taking on how to orient strip wood flooring if the non-load bearing junction is a party junction. The effect of coverings can be added to the effect of the (investigated) toppings on which they are applied. However, this is probably not the case for toppings that do not have a face layer of wood. Errors made below 100 Hz through "indirect noise" lead to a conservative estimate of the improvement.
In the near future, the knowledge gained in this paper will be incorporated into the NRC software tool, *sound***PATHS**, to predict performance based single number ratings for rooms one above the other or side-by-side with floor treatments in wood framed construction.

## 6 ACKNOWLEDGEMENTS

Great thank goes out to the consortium members of the fifth phase of the project "Flanking Sound Transmission in Wood Frame Multi-Family Dwellings" for their valuable input and patience.


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*Table 1 - Description of base flanking assembly*

| Floors | Walls |
|---|---|
| • 19 mm OSB subfloor<br>• 300 mm deep wood I-joists at 406 mm o.c.<br>• 150 mm cavity insulation<br>• Resilient channels at 406 mm o.c.<br>• Two layers of 16 mm fire rated gypsum board | • Two layers of 16 mm fire rated gypsum board<br>• 2x4 studs (89 mm deep) at 406 mm o.c.<br>• 90 mm cavity insulation<br>• Resilient channels at 610 mm o.c.<br>• One layer of 16 mm fire rated gypsum board |

*Table 2. Overview of assemblies evaluated in this study.*

| Topping/Covering | None ( ) | Vinyl (V) | Carpet (C) | Click Laminate (L) | Engineered Wood flooring (E) | Ceramic Tiles (T) | Strip wood perp. to joists (S1) | Strip wood para. to joists (S2) |
|---|---|---|---|---|---|---|---|---|
| None (9A) | 9A | 9A-V* | 9A-C* | 9A-L | 9A-E | | 9A-S1 | 9A-S2 |
| Wood raft (9C) | 9C | 9C-V | 9C-C | 9C-L | 9C-E | | 9C-S1 | |
| OSB overlay (9D) | 9D | | | | 9D-E | 9D-T | 9D-S1 | |

*patch, not tested for airborne sound insulation

*Table 3. Decsription of evaluated toppings and coverings.*

| Toppings | Coverings |
|---|---|
| • 9C-Wood raft: 16 mm plywood stapled to 16 mm OSB floating on 9 mm closed foam mat. (20 kg/$m^2$)<br>• 9D-OSB overlay: 19 mm OSB overlay installed perpendicular to subfloor fastened with staples, (11 kg/$m^2$) | • V: 1.6 mm thick vinyl at 1.5 kg/$m^2$<br>• C: 7 mm thick carpet at 1.6 kg/$m^2$<br>• L: Click laminate flooring on 3 mm thick underlayment (~9 kg/$m^2$)<br>• E: Engineered wood flooring (~10 kg/$m^2$)<br>• T: Ceramic tiles: 330x300x8.4 mm tiles at 19 kg/$m^2$<br>• S1: Strip wood flooring (with long axis perpendicular to joists) (~13 kg/$m^2$)<br>• S2: Strip wood flooring (with long axis parallel to joists ~13 kg/$m^2$) |

*Table 4. Summary of path names, directions, and shielding conditions*

| Name | Direction | Junction | Shielding | Note |
|---|---|---|---|---|
| direct | vertical floor-ceiling | non-load bearing and load bearing | all walls of upper and lower rooms shielded | |
| diag_lb | diagonal floor-wall | load bearing | walls in upper room shielded | Same as vertical load bearing floor-wall path. Diagonal floor-ceiling path can be neglected. |
| diag_nlb | diagonal floor-wall | non-load bearing | walls in upper room shielded | Same as vertical non-load bearing floor-wall path. Diagonal floor-ceiling path can be neglected. |
| hor_lb | horizontal floor-floor | load bearing | walls of source and receive room shielded | Floor treatment effect assumed to be same as for load bearing horizontal floor-wall |
| hor_nlb | horizontal floor-floor | non-load bearing | walls of source and receive room shielded | Floor treatment effect assumed to be same as for non-load bearing horizontal floor-wall |

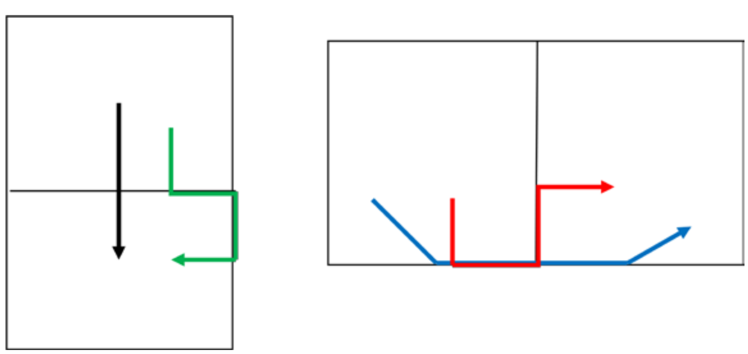

*Fig 1- Paths affected by floor treatment for a) rooms one above the other (black: floor-ceiling, green: floor-wall (loadbearing or non-loadbearing)) and b) rooms side-by-side (blue: floor-floor, red: floor-wall (loadbearing or non-loadbearing)).*

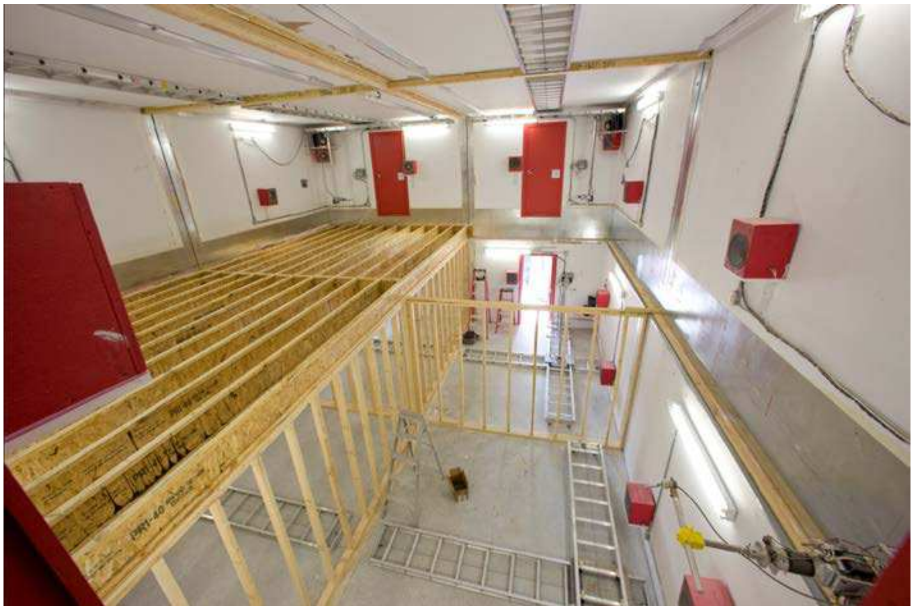

*Fig. 2. Eight-room NRC-Flanking Facility with computer controlled microphone robots and loudspeakers in each room. This photo shows the base wood framed assembly under constuction. The walls parallel to the joists are non-load bearing; those perpindicular to the joists are load bearing.*

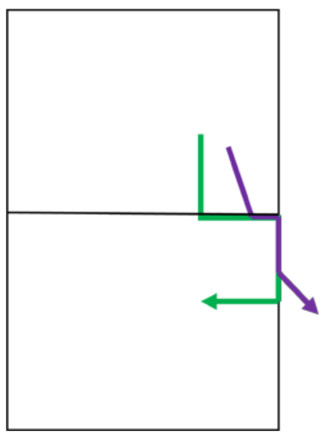

*Fig. 3. Alternate path measurement for rooms one above the other (green: vertical floor-wall path of interest, purple: captured equivalent diagonal floor-wall path).*

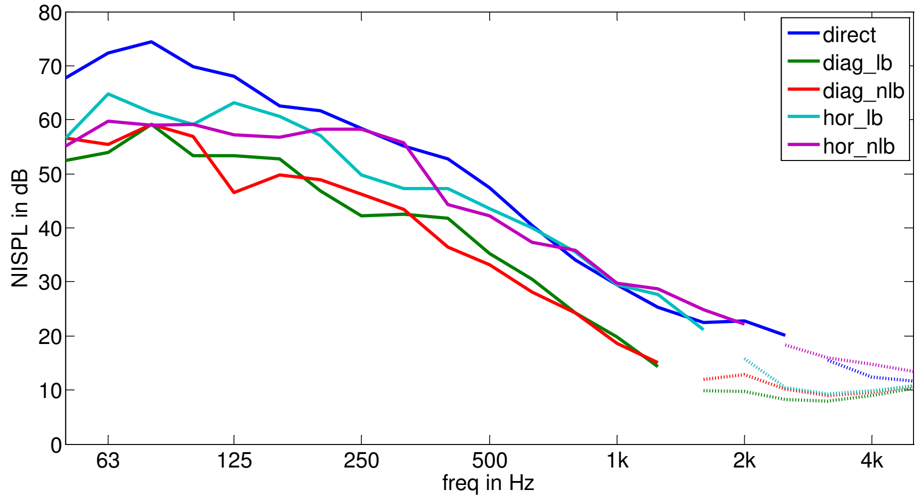


*Fig. 4. Normalized impact sound levels for carpet on bare sub-floor for five paths as indicated in caption. The dotted lines denote data influenced by background noise.*

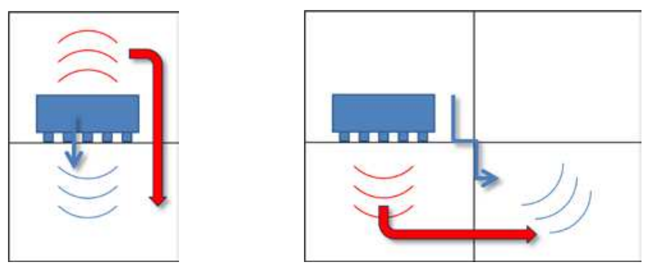

*Fig. 5. Sketch illustating "indirect noise" for vertical (left) and diagonal (right) path measurments. The blue wave fronts and blue arrows depict the levels and paths of interest. Red wave fronts and arrows depict contamination by "indirect noise".*

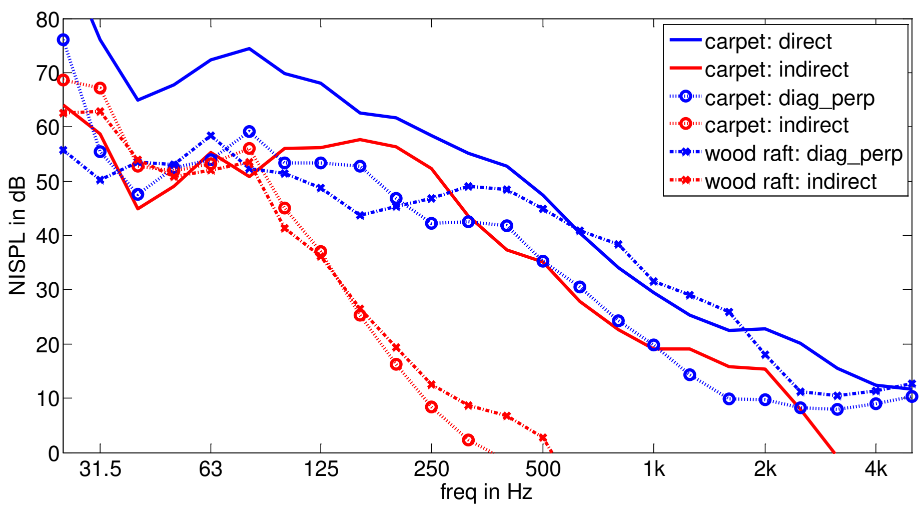


*Fig. 6. Magnitude of impact paths of interest (blue cureves) and indirect impact sound (red curves) for carpet (direct and diag_perp) and for wood raft (diag_perp).*

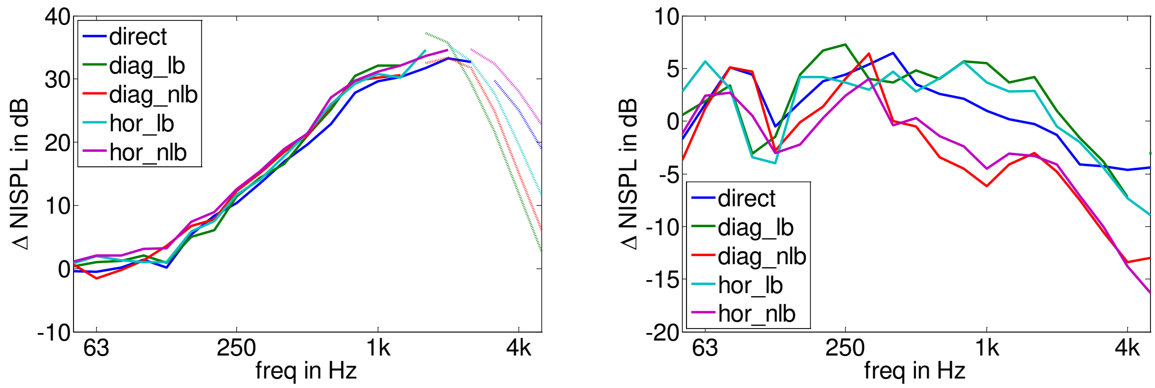


*Fig. 7. Effect of carpet (left) and strip wood flooring (right) on bare floor assembly 9A for five different path directions. A positive number means an improvement of sound insulation properties. The dotted lines denote data influenced by background noise.*

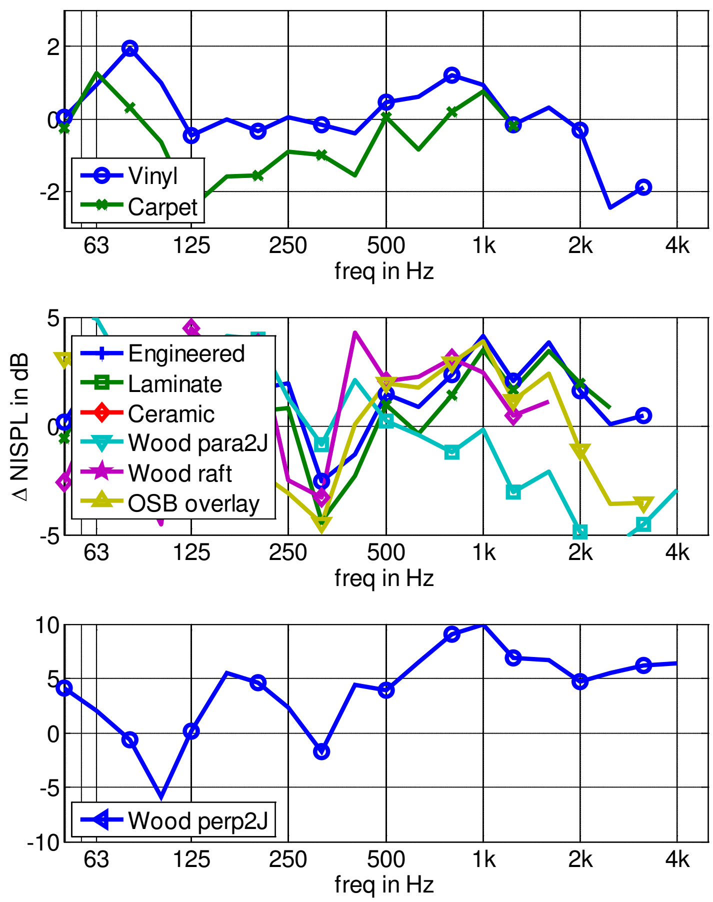


*Fig. 8. Normalized impact sound level differences of floor treatment improvement between averaged load bearing and averaged non-load-bearing cases, classified in three groups. top: locally reacting, middle: mixed, bottom: globally reacting*

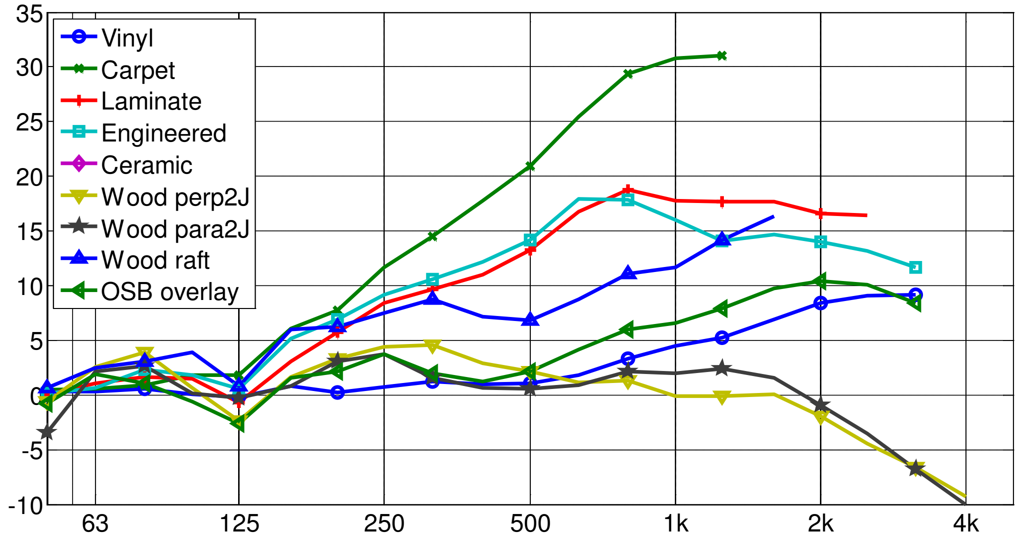


*Fig. 9. Improvement of floor treatments on impact sound levels relative to bare floor averaged over all five path directions*

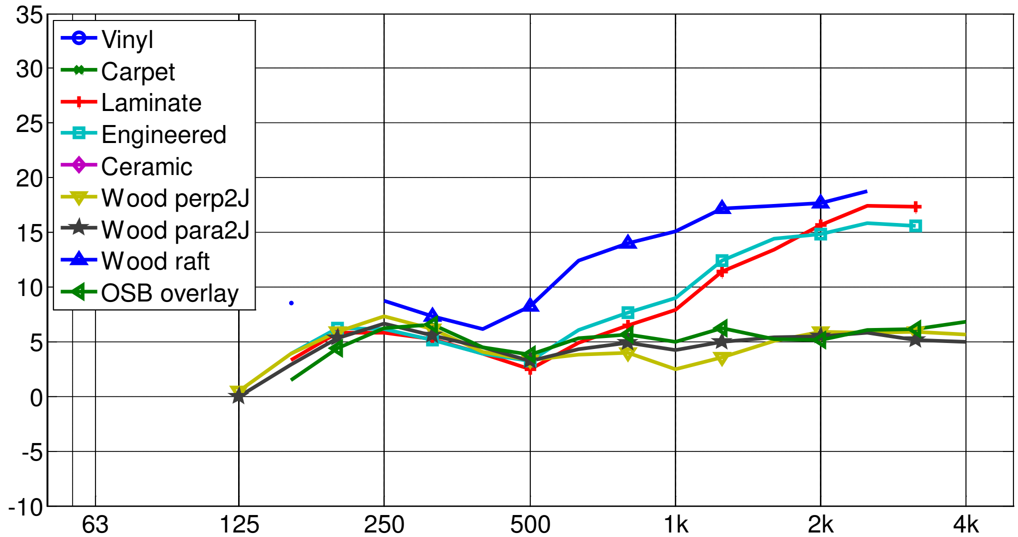


*Fig. 10. Improvement of floor treatments on airborne sound insulation relative to bare floor averaged over all five path directions*

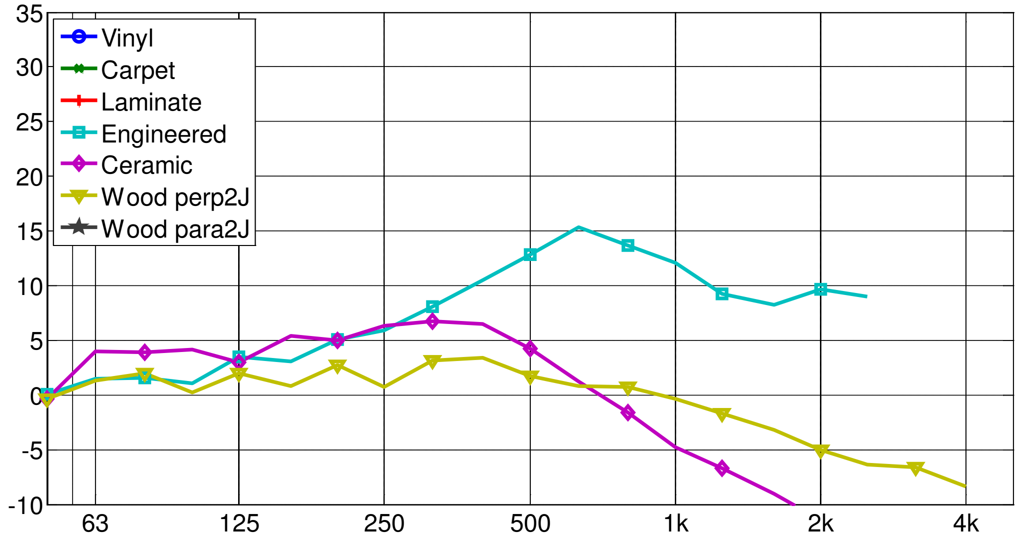


*Fig. 11. Improvement of floor treatments on impact sound levels relative to OSB overlay floor (9D) averaged over all five path directions*