Sound insulation in multi-story timber buildings

Kessel, Martin H.[1], Sierig, Ute [2]

ABSTRACT

During on an extensive investigation of a multi-story timber building with light-frame construction, several stages of the building process and their impact on sound transmission were observed. The sound insulation properties of the building components were measured before and while the buildings were occupied. Furthermore, interviews with the occupants were conducted. This procedure made it possible to compare measured sound insulation levels with their subjective evaluation. All occupants were happy with the sound transmission qualities of the buildings. The measurements show that sound insulation in the buildings meets the requirements of DIN 4109, except at locations in which construction details deviated from those specified.

ACOUSTIC MEASUREMENTS IN A MULTI-STORY APARTMENT BUILDING

Acoustic measurements were made of walls and ceilings separating adjacent apartments and dividing apartments from the corridors and stairwells. The same construction details, relative to sound insulation, were used in all five buildings of the complex (see Fig. 1).

Three major types of partition walls were used in the buildings. One building was separated from another with the wall detail in Fig. 2. This wall is composed of two conventional light-frame walls, separated by a 20 mm air space. The second detail, shown in Fig. 3, was used to separate an apartment from the staircase. Again, two conventional light-frame walls are separated by a 20 mm air space, but the wall on the apartment side of the partition is more lightly framed than the other. Adjacent apartments were separated with the detail shown in Fig. 4. As shown, this wall detail does not include gypsum or cement-based particleboard panels inside the partition.

Figure 1 - View of Buildings

In principle, the partition walls between apartments (Fig. 4) are the more efficient design, due to the absence of inner panels, as used in the other two walls. Since the detail assures that the panels are widely separated, errors during construction that might decrease sound insulation, could be minimized successfully. The exterior partition walls (Fig. 2) showed slightly better sound performance, but at greater expense in materials and labor.

Partition walls facing the stair case have a problematic detail, in that the boards within the wall have too little spacing. Errors during construction decrease the overall sound insulation for these walls, because of the creation of sound bridges when small objects (stones and wood chips) fall between the panels.

Partitions within an apartment (details not shown) have only limited ability to control sound transfer, since floor, ceiling, and other secondary paths also play significant roles. Therefore an improvement in overall sound insulation requires a reduction of those impacts, e.g. the usage of high-quality doors and an improved ground plan design.

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[1] Prof. Dr.-Ing. Martin H. Kessel, Technical University of Braunschweig, Institute for Building Engineering and Timber Construction, Schleinitzstrasse 21 A, 38106 Braunschweig, Germany.
[2] Dipl.-Ing. Ute Sierig, Technical University of Braunschweig, Institute for Building Engineering and Timber Construction, Schleinitzstrasse 21 A, 38106 Braunschweig, Germany.

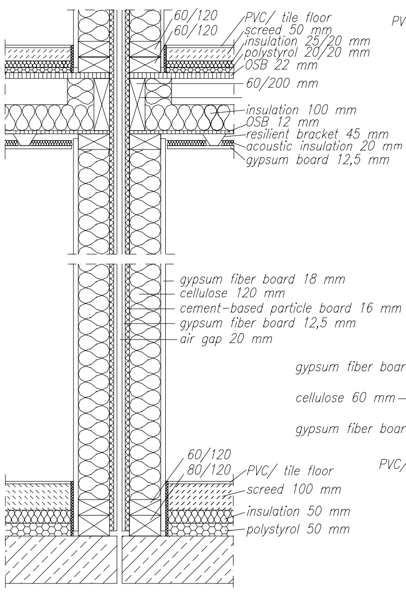

Figure 2 – Wall between buildings

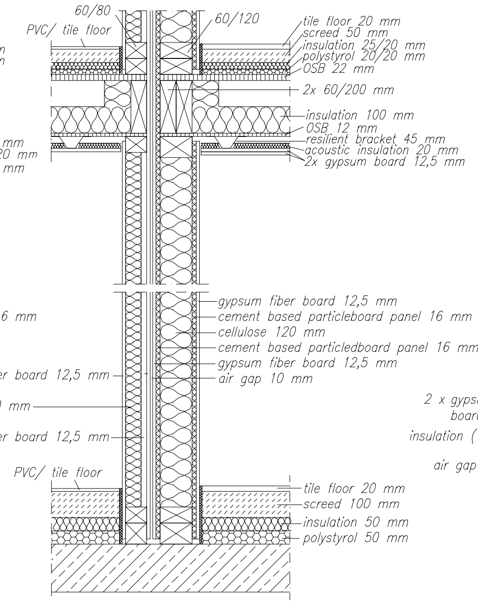

Figure 3 – Wall between apartment and staircase

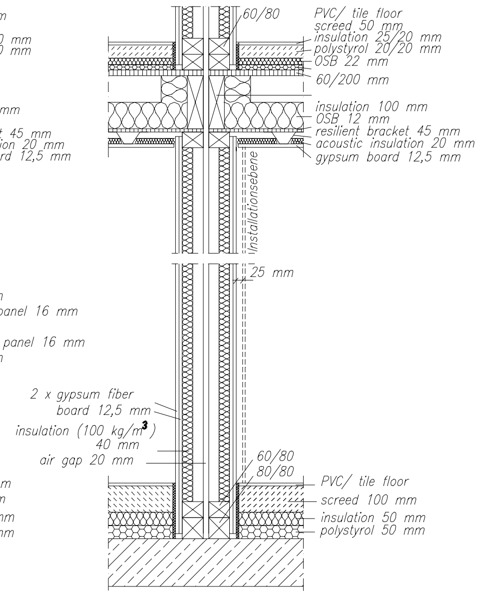

Figure 4 – Wall between apartments

If tile or other rigid floor covering is used on timber joist floors, joints with the walls and floor penetrations (plumbing) must be constructed precisely. An increase of up to 2 dB in sound transmission can be expected for rigid flooring, even with precise construction. In general, the impact sound insulation is poor at low frequencies, and it improves at 400 Hz. The sound transmission performance of wood-framed floors with tile floor finish is strikingly similar to that of solid slabs. The positive effect of soft floor covering, such as carpet, on problems with high frequency sounds were also observed with the PVC floor covering used in these buildings. Results of the sound measurements prove that the biggest problem with timber joist floors relates to their impact sound performance and therefore mainly to low frequencies.

One year after the first tenants moved in, several sound measurements were carried out, depending on their importance and the local possibilities. In general no substantial change of sound transfer through walls and floors could be observed as a result of building occupancy. This shows that neither the partially existing carpet (installed by the tenants) nor the hardened concrete screed had an impact on the airborne sound insulation of the timber joist floor. Improvements in impact sound insulation could be observed, compared to be conditions one year before. A carpet over PVC flooring decreases the impact sound transfer significantly, influencing mainly the moderate and high frequencies. Low frequency sound transmission can not be improved by those steps and remains the weakness of this floor system.

Comparing airborne sound insulation with the impact sound insulation of floors, the following relation can be found: $R'_w \approx 110 - L'_{n,w}$, where R'_w is the weighted sound reduction index and $L'_{n,w}$ is the weighted normalized impact sound pressure level. This approximation is true for rooms with PVC floor covering, whereas greater differences can be observed for floors with tiling. The difference between airborne sound insulation and impact sound insulation for the installed floors is greater for PVC than it is for tile. Therefore, concerning timber joist floors, tile has a greater negative effect on impact sound insulation than on air sound insulation. Solid slabs are weak in resisting impact sound transmission, especially in the high frequency range. Yet, they are effective insulators of low frequency sound. Floating screed is effective in reducing high frequency sounds. So, a combination of floating screed on solid slabs is effective over a wide range of frequencies. By contrast, wood joist floors are good insulators of high frequency sounds. So the application of floating screed over a wood joist floor system is not so effective.

For the floor construction used in these buildings (wood joist system), the calculated impact sound levels exactly matched those levels measured on site. A prediction of the normalized impact sound level, according to DIN 4109, is possible by approximation of the complete floor construction to the samples given in the standard. Often calculated values do not accurately predict the performance of the actual floor system, resulting in relatively high factors of safety.

For the buildings tested, in most cases the minimum requirements for horizontal and diagonal impact sound insulation between staircases and occupied rooms were not met. The reasons can be found in the incorrect installation of the moldings at the base of the walls, as well as in the way stair risers and landings were connected to adjacent elements. For satisfactory impact sound insulation, not only the floors are of importance, but also influences like attachments due to unfavorable floor plans or details and improper construction technique must be considered. Table 1 shows an overview of the influence of several parameters on horizontal and vertical transmission of impact sound. Parameters that affect airborne sound transmission are described in Table 2.

Table 1 – Impact sound transmission parameters

Parameter	**Influence on impact sound insulation**	
	Vertical	**Horizontal**
Floating screed application	+ ca. 23 dB (ceiling beams continuous between rooms)	0 (ceiling beams continuous between rooms) + ca. 19 dB (staggered arrangement)
Increase thickness of screed layer	+ ca. 1 dB	- ca. 2-3 dB possible
Occupied condition	+ ca. 2-3 dB	0
Floor covering: tile or PVC	+ Advantage of PVC compared to tiles: 2-5 dB	+ ca. 3-5 dB (PVC, ceiling beams continuous between rooms)
Suspended ceiling added to bare floor with floating screed	+ ca. 1 dB lath without insulation + ca. 6 dB resilient bracket without insulation + ca. 7 dB resilient bracket with insulation	+ ca. 4 dB resilient bracket without insulation
Floors with discontinuous beams	0	+ ca. 24-33 dB + ca. 3-10 dB sound bridge within wall
Unplanned secondary paths	- up to 4 dB airborne sound through interior doors	- airborne sound through interior doors
Construction errors	- ca. 2-10 dB sound bridge at wall molding	- ca. 2-3 dB sound bridge at wall molding - sound bridge at staircase wall

+ Improvement, - Deterioration, 0 No change of sound insulation

Table 2 – Airborne sound transmission parameters

Parameter	**Influence on airborne sound insulation of**	
	Floors	**Walls**
Floating screed application	+ up to 18 dB sealed openings	+ ca. 1-4 dB closed leaks
Increased thickness of screed layer	+ 1-2 dB	0
Floor covering: tile or PVC	+ Advantage of PVC to tiles: 1-5 dB	0
Suspended ceiling added to bare floor with floating screed	+ ca. 2 dB lath without insulation + ca. 3 dB resilient bracket without insulation + ca. 4 dB resilient bracket with insulation	0
Joint sealing	+ ca. 0-2 dB	+ ca. 4 dB interior partition walls
Unplanned secondary paths	- up to 4 dB airborne sound through interior doors	- airborne sound through interior doors
Construction errors	- ca. 5-8 dB sound bridge at wall moldings	- ca. 3-4 dB sound bridge at staircase wall
Furniture	0	- ca. 2-3 dB if extensively furnished

+ Improvement, - Deterioration, 0 No change of sound insulation

In addition to the series of tests, the tenants were interviewed to record their perceptions of sound transmission. Results of the interviews give an overall impression of the perceived sound insulation in the observed buildings and thus for currently available timber housing. Furthermore, specific sound sources produced within the house could be evaluated and interpreted.

The interpretation of the tenants perceptions of sound depends on information such as the usage of the rooms, the apartment's floor plan, and other parameters (the times that the family is at home, the number of children, etc.). All tenants were satisfied with the overall sound insulation of the building. Several isolated problems were due to improper usage by the tenants (late night parties) or by avoidable planning and construction errors (sound bridges).

According to both measurements and tenants perceptions, the primary path of air sound transfer is between the apartments and the staircase. Voices in the staircase are noticed twice as often as a hi-fi system used in a neighboring apartment. Since the level of nuisance is not significantly higher, a greater acceptance of every-day noise from the staircase was observed. Sound insulation between apartment units is more important to the tenants than that between the apartment and the staircase. The same observations could be made for sounds that were produced by impact sound stimulation. Those sounds were noticed more often when coming from the staircases than from adjacent apartments, but they were less disturbing than the same or less noise from adjacent apartments. Stepping or trampling in the staircases were seen as normal activities and thus were easier to accept. Measurements showed that construction elements facing the staircases are problematic with respect to impact sound insulation. On the other hand, measurements of sound transmission through the floors showed better performance than between the staircase and the apartments. Nevertheless, tenants were more sensitive to noise from another apartment, regardless of its location, than to noise from the staircase. Interview statements indicate that airborne sound transmission through floors is an important consideration, in addition to impact sound transmission. But airborne sound insulation is harder to achieve in floors than in walls. The advantage in wall construction can be found in the complete decoupling of the two shells by using continuous separating joints. For floors, this decoupling is possible only with the installation of resilient suspended ceiling. Impact sound measurements indicate acceptable perception of normal stepping sounds through partition floors. This results match statements by the tenants. In principle impact sound are noticed more strongly than airborne sound.

To optimize sound transfer between apartments, rooms should be isolated by extending the sound paths. Since staircases are critical locations due to their frequent use, they should be located outside the living area. During construction and installation of floors, attention must be drawn to perfect work, in order to provide impact sound insulation. Connections between structural components must be designed with consideration for the requirements of airborne sound insulation. Good overall sound insulation depends on every aspect of the building's structural system and details.

EFFECTS OF INCREASING WALL STRENGTH ON SOUND INSULATION

Multi-story buildings place higher demands on light-frame construction than do smaller, single-family residential buildings. Increasing the number of studs in a light-frame wall to increase its strength also increases its stiffness and its mass. But due to its higher stiffness and an increase in the number of sound bridges, negative impacts have to be expected. The number of sound bridges and their spacing are more important to a change of the overall sound insulation than are changes in the mass of the wall or in the size of the contact area between the sheathing and the studs. Doubling the number of sound bridges by reducing the stud spacing leads to a deterioration of the overall sound insulation. The smaller the effective sheathing width, the less the sheathing will dissipate energy through vibration due to sound induction. Rather, the sound induced energy will be transmitted directly through the studs. Better results can be achieved by a staggered arrangement of the studs on the sole plate, such that only every second stud is in contact with the sheathing on one side of the wall.

Concerning bending stiffness, it can be expected that an arrangement of multiple thin layers of sheathing yield better sound insulation than an equivalent thick layer. Gypsum fiberboard shows better sound insulating behavior than OSB, which is due to its higher mass. An additional sheet of sheathing on only one side of a wall gives significantly higher sound insulation at low frequencies. An increase in mass of the wall is less effective in a wall that already has high mass than in one with low mass. The most economic method is to use two layers of sheathing on each side of the wall. It is also slightly favorable to use the same sheathing thickness and materials on both sides of the wall to balance the mass. An investigation of the fasteners showed that they have a negative effect on sound insulation of a wall. The kind of fasteners is of secondary importance. The use of staples has a slight advantage compared to the use of screws. It is not advised to use glued connections since they have a strong negative impact. The more fasteners are used, the stiffer becomes the construction and the worse becomes its sound insulation behavior. The effectiveness of cavity insulation is low if wall elements are screwed together. In this case, due to the rigid connection of studs and sheathing, most of the sound is transferred through this path and not through the cavity area. The influence of the cavity insulation increases with increased decoupling of the sheathing from the studs.

FAULTY PENETRATIONS AND SECONDARY SOUND PATHS IN TIMBER JOIST FLOORS

Light fixtures are often installed in bare floors or in suspended ceilings. If installed after construction it can happen that removed parts of the floor are not properly replaced. Measurements in this research showed no influence of different installation methods for the fixtures. Disturbances from small areas of the ceiling can be neglected. In principle, puncture faults do not have a negative impact on the overall airborne sound insulation, if they are sealed at the exterior side. Compared to the perfect condition, these faults mainly influence the impact sound insulation.

If sealed drainage pipes are located in the floor cavity, they do not have a significant negative impact. Faulty installation of pipes to direct airborne sound transfer along the pipes and therefore to a great deterioration of the component's sound insulation. For this reason, leakage around the pipes must be sealed and the pipes must be insulated inside the cavity. Leakage means that air channels reach from one side of the floor to the other, such that airborne sound is transferred to the next room without transformation into structure-borne sound. Since even small joint have a great impact on a component's sound insulation, they should be prevented by cautious detailing and by faultless installation. Fresh water pipes are usually installed directly on the bare floor, under the screed. Thus they lie right in the impact sound insulation. During pipe assembly, unplanned cross points or multiple pipe layers can develop. If the impact sound insulation is not sufficient, the pipes can create a sound bridge between the floating screed and the bare floor. Furthermore, faulty application of the floating screed can lead to large sound bridges because of direct contact between the wall and the floor. Cavity installations that are not connected to both the floor and the screed, do not influence the floor's airborne sound insulation or impact sound insulation. Only an accumulation of pipes that create direct contact between the screed and floor sheathing results in deterioration of impact sound insulation. The impact sound pressure level rises over a frequency range from 315 Hz to a maximum of 2000 Hz. The stiffer the sound bridge is, the greater is the deterioration.

COLLECTION AND EVALUATION OF SOUND DATA IN WOOD CONSTRUCTION

Kessel and Sierig (1999) developed a catalogue containing 1167 sound transmission measurements of building components. This data was sorted and analyzed for use in extending specifications for design of sound insulation according to DIN 4109. Furthermore this data makes it possible to predict the general sound insulation characteristics of the building with need for extensive measurements. By a comparative examination of the sound insulation quality of various types of construction used nowadays, uncertainties can be reduced by a tendentious assessment and a comparison of variables. The catalogue helps in the evaluation of a component's sound insulation properties during the planning processes. Also it supports choice of the right components for particular requirements. The catalogue includes an assessment of the effects on sound transmission quality of variations in certain construction parameters.

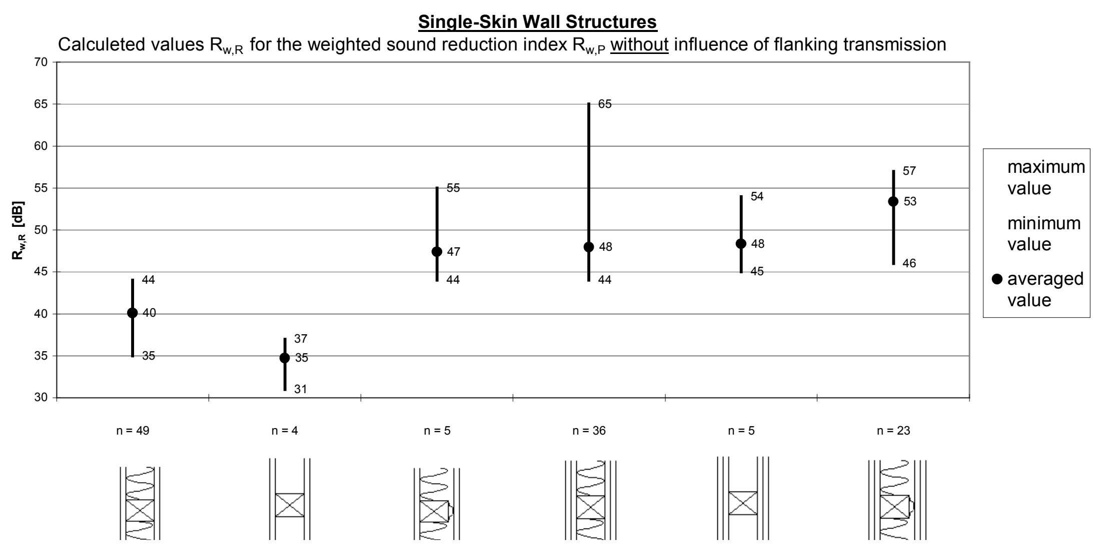

Figure 5 - Sound Insulation of single-skin walls in the laboratory without side transfer

The effectiveness of insulating hollow areas in walls mainly depends on the kind of connection between the studs and the sheathing. Improvement of the sound insulation can be achieved by application of multi-layer sheathing (Figure 5). The amount of improvement depends on the number of layers, their material, and the sort of fasteners used. Therefore sound insulation levels can vary within a great range. These measures are effective and economical only up to a certain level. A comparison of measurements for single-skin walls on site and in the laboratory with no side transfer shows that a wall's sound insulation on site is generally 2 dB lower.

An analysis of measurements on two-skin walls makes it clear that level of improvement of sound insulation levels increases with an improved wall design. As the quality of a component's sound insulation increases, the influence of boundary conditions and construction details also increases (Figure 6). For instance, sound bridges in the form of continuous joints can drastically reduce the insulation of the wall. Greater tightness against direct airborne sound transfer can be provided by sheathing every wall shell on both sides. The average rated sound insulation level is lower on site where sound transfer through side components is allowed.

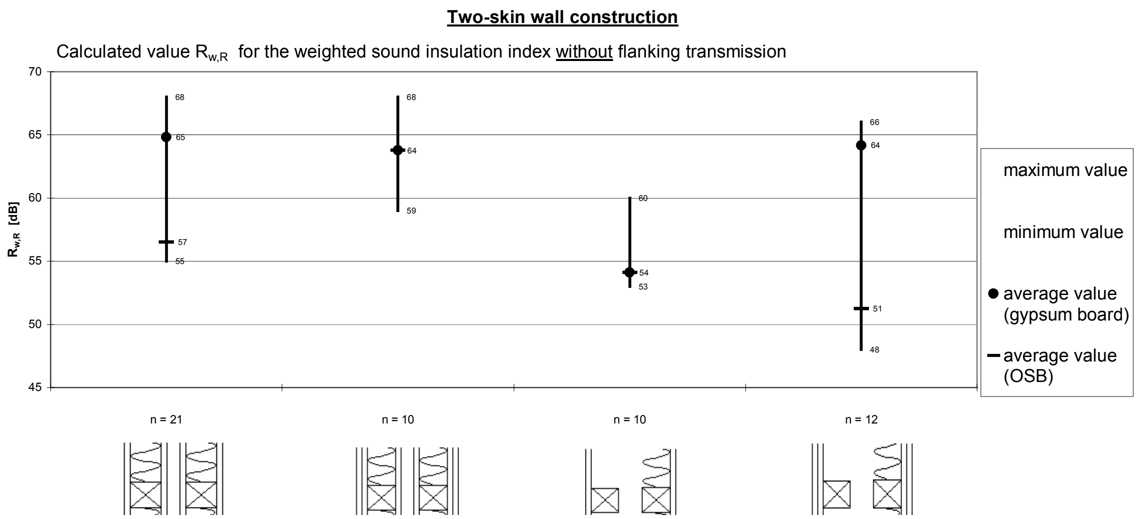

Figure 6 - Sound insulation of two-skin walls in laboratory without side transfer

It is no problem to achieve good airborne sound insulation with floor construction used nowadays (Figure 7). Any kind of covering can improve a bare floor's sound insulation. It is important to separate the bare floor from the heavy part of the covering (the screed). In principle, sound insulation improvement can be achieved by increasing the mass of the floor, whereas its effectiveness increases only to a certain level. In the laboratory, side transfer does not caused significant differences in the overall sound insulation. Also, the type of suspended ceiling has influence only on the level of airborne sound transmission.

The installation of additional shells, coverings with additional mass, or decoupled suspended ceilings can improve the impact sound insulation significantly. Thus the best result for a timber joist floor can be achieved with additional mass and covering, as well as a resilient suspended ceiling. The impact of additional mass is more important for transfer of impact sound than it is for airborne sound. Since a bare timber joist floor has a relatively low dead weight, it is very effective to increase the impact sound insulation by adding weight (Figure 8). Resilient suspended ceilings improve impact sound transmission through the floor. Obviously, measured values of impact sound transmission are lower if side transfer is included. Thus the effect of side transfer on impact sound insulation is critical. In principle impact sound measurements made on site are about 1-4 dB worse than those measured in the laboratory without side transfer. Laboratory results with side transfer generally match on-site results.

For exposed timber joist floors the mass necessary to provide sound insulation must be applied on top of the floor, as it is the only completely continuous layer within this kind of construction. Leakage, and therefore direct airborne sound transfer, has to be absolutely prevented. In total, wet screed has certain advantages that strongly depend on the application on site. New, dry-screed insulation systems reach another level than those that were normal in the past. Thus improvements by an application of wet screed can also be achieved with modern dry-screed insulation systems without the problems associated with use of water over a wood floor.

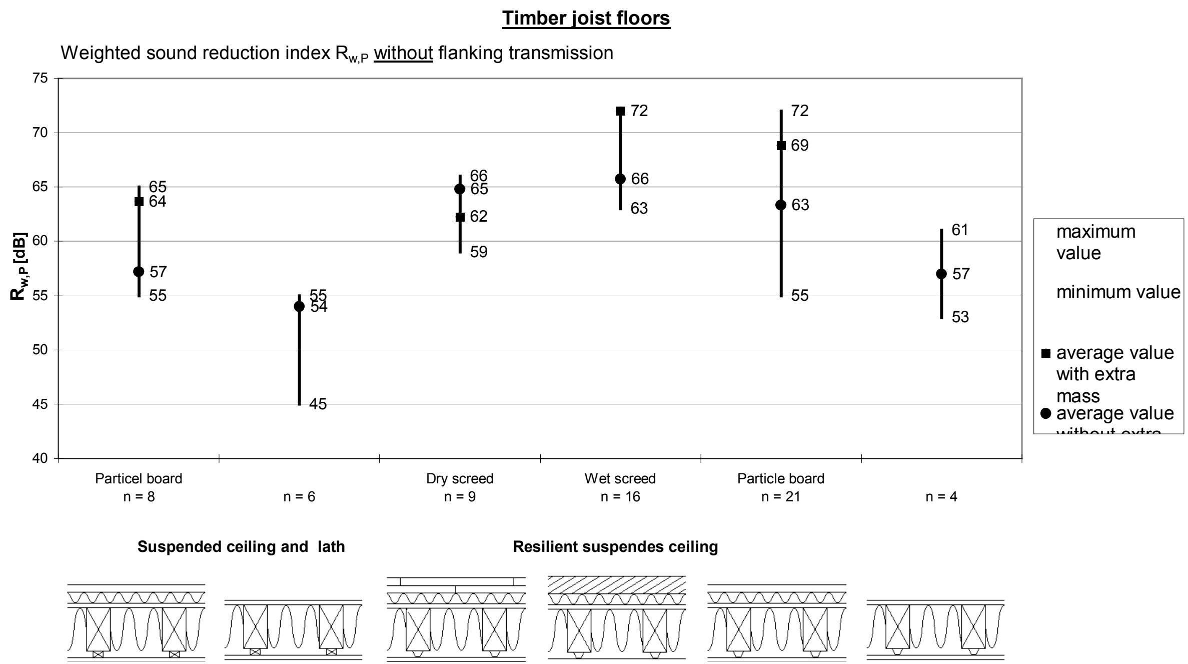

Figure 7 - Airborne sound insulation of timber joist floors without side transfer

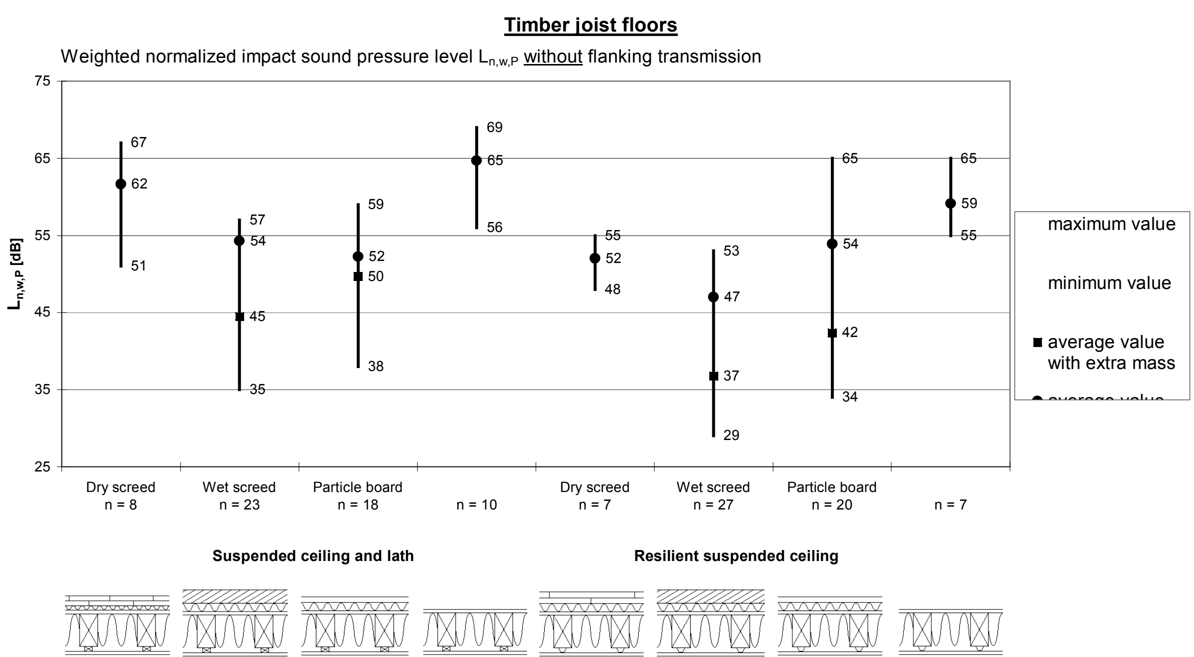

Figure 8 - Impact sound insulation of timber joist floors in laboratory without side transfer

LITERATURE

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