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ADEQUATE IMPACT SOUND PROTECTION IN LIGHT CONSTRUCTION AND SOLID FLOORS – SEQUENCE OF LAYERS. MATERIALS SELECTION AND DIMENSIONING

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ABSTRACT: Based on the European codes OENORM and DIN on impact sound requirements with values between 50 dB and 46 dB in multi-storey residential buildings, floor constructions are listed that can meet these requirements. Materials parameters that play an essential role are: thickness, density, e-module, dynamic stiffness and values that derive from them (mass, bending strength, resonance frequency, coincidence frequency). The comparison between light construction and heavy solid floors reveals that different dimensions and materials are required in the individual layers. When built as a floating floor structure, it is easier to achieve adequate sound protection values with heavy floors, because of their huge mass and bending stiffness. In this case acoustic adjustment can easily be accomplished. In light construction floors the relatively small area mass and bending stiffness in the raw floor constitutes a disadvantage in terms of impact sound absorption. Apart from the acoustic properties of the floor structure, the influence of the flanking structures (e.g. walls) and their bearing situation (joining technique) must be taken into consideration. Further investigations show that both floor types can meet high requirements, although differences in high and low frequency ranges are clearly noticeable. The underlying causes are also subject of this publication.

KEYWORDS: impact sound, light construction, low frequency, dynamic stiffness, multi-storey residential buildings

1 INTRODUCTION

The OENORM and DIN standards have their origins in the concrete and brick construction industry. The codes are adapted to these materials and structures, and the standards can easily be reached, if the construction quality is flawless. Exterior noise immission, sound-technologically favourable floor plans and room functions must be taken into consideration. These factors are of particular importance in multi-storey residential buildings. Light construction parts (gypsum boards, light timber construction, timber floors) are described in the above-mentioned codes, but these specifications are not generally applicable to light constructions. We took as a starting point the specifications in the codes for heavy and massive constructions and adapted the results of our investigations and our considerations to timber constructions (light constructions), taking the physical principles into account. These findings were verified by laboratory and building measurements. In general multi-layered structures with adequate dimensions are required to meet the stringent specifications in the OENORM and DIN codes for impact noise protection.

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2 PROJECT DESCRIPTION

If we want to apply the Code practices to light construction, we are confronted with some acoustic challenges. For heavy solid concrete construction, the curve profile of the impact sound insulation starts at the lower frequency range (around 100 Hz) compared to light construction (wood construction) with slightly higher values. In the case of a heavy single wall construction, the curve profile is shallower (6-9 dB per octave) than for multi-shell light construction (9-12 dB per octave). This means that the acoustic behavior changes with different static systems. What this means in terms of light construction and which solutions are viable, is presented in this publication.

2.1 REQUIREMENTS RELATED TO THE STANDARDS (AUSTRIA – GERMANY)

The airborne and impact sound protection requirements for floors in residential buildings are in Austria according to OENORM 8115

- weighted standardized impact sound level
  $L_{nT,w}$ = $\leq$ 48 dB
- weighted standardized sound level difference
  $D_{nT,w}$ = $\geq$ 55 dB

in Germany according to DIN 4109

- weighted standardized normalized impact level
  $L'_{n,w}$ = $\leq$ 50 dB
- sound reduction index value
  R'_{w} = $\leq$ 54 dB

2.2 ESSENTIAL LAYERS IN FLOORS

The basic principle of multi-layer constructions is as follows (simplified model): mass – spring – mass. This model (raw floor and additional layers) is applied to achieve the required impact sound standards (Figure 1).

In multi-layered construction parts, the resonance frequency must be below 100 Hz, favourably not higher than 80 Hz. The matching and dimensioning of the various floor layers is essential.

The formula for frequency-dependent improvement of impact noise absorption is as follows:

$$\Delta L = 30 * \log\left(f / f_{res}\right) \quad in\ dB \qquad (1)$$

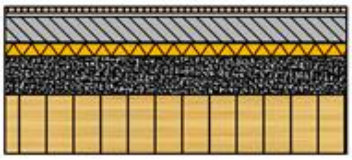

Figure 1: *Multi-layer floor construction*

Possible layers from top to bottom:
- Floor cover (wood, tiles, carpet, etc.)
- Base layer (cement floating screed, anhydrite, poured asphalt, dry screed e.g. wood boards)
- Mass impact sound insulation layer (fibre boards, insulation foams etc.)
- Mass and levelling layer (fill materials e.g. gravel, sand, expanded clay, etc., foam concrete, polystyrene concrete etc.)
- Raw floor (concrete slap, concrete or brick hollow floor, glued and cross-laminated timber floor, wood-concrete composite floor, timber cavity floors, timber beam floors)
- Suspended ceiling (elastic suspension + cavity dampening + board material (gypsum board, gypsum fibre, wood-based boards)

2.3 RAW FLOOR TYPES AND THEIR PROPERTIES

The diagram (Figure 2) shows the norm impact sound level reference floors as compared to raw floors.

Comparison to raw floor specimen
- Timber beam floor ÖNORM ISO 140-11 — $L_{n,r,t,0,w}$ = 72 dB
- Glued laminated timber — $L_{n,r,tv,0,w}$ = 82 dB
- Massive floor specimen — $L_{n,r,0,w}$ = 78 dB

2.3.1 Massive Concrete floors

For massive raw floors with area masses m' ≥ 200 kg/m² applies:

$$L_{n,eq,w} = 164 - 35 \log m' \text{ in dB} \qquad (2)$$

$L_{n,eq,w}$ = equivalent weighted normalized impact sound level of raw floor.

If the mass value is between 300 and 600 kg/m² the single value specification $L_{n,eq,w}$ lies between 78 dB and 65 dB. The progression of the impact sound level values is unfavorable with increasing frequencies, when compared to the weighted norm curve. Correspondingly EN ISO 717-2 results in C_I = -10 dB or -11 dB. By mass increase the required sound protection value cannot be achieved (as it is uneconomical) and in addition the unfavorable frequency progression remains. The effect of filling material is rather small, because the relative mass increase is crucial. The doubling of the mass leads to an improvement of about 10 dB.

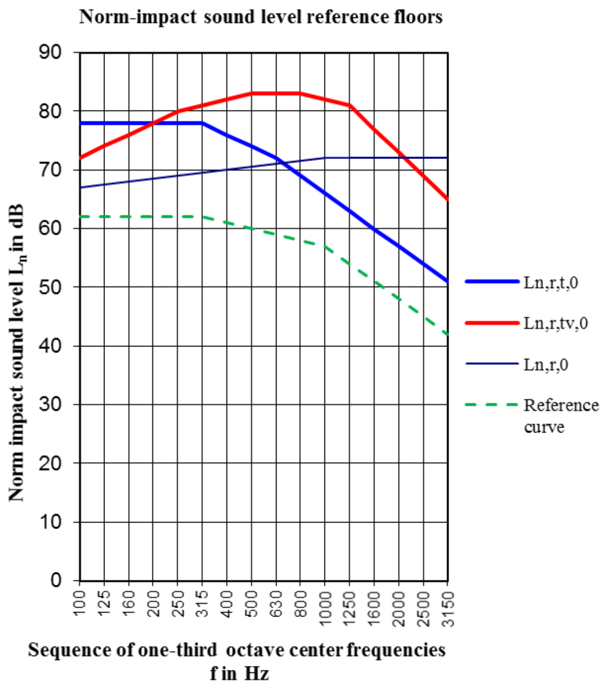

Figure 2: *Multi-layer floor construction*

2.4 CROSS LAMINATED OR GLUED LAMINATED TIMBER FLOORS

The standard floor thickness of this floor type ranges from 120 mm to 220 mm. This constitutes an area-related mass of m' = 60 to 120 kg/m². This results in values $L_{n,tv,0,w}$ = 88 dB to 80 dB

The normalized impact sound level in massive wood elements is considerably more favorable (C_I = -5 dB), because of the low surface hardness in the high frequency range (beyond about 1000 Hz). Due to the relatively low masses the calculated impact sound levels are generally higher than in massive floors (e.g. concrete, brick). To date mass dependence in massive timber floors has not been taken into consideration in literature. Due to numerable measurements and investigations the $L_{n,w}$ dependence of raw floors could be expressed in an equation in two different mass ranges. Additional weighting by filling material (between 60 to 100 kg/m²) is generally required to meet the sound protection values according to OENORM and DIN. Compared to heavy concrete floors, the mass increase in these timber floors shows a higher sound protection effect.

Formula and Diagram

Raw floor: concrete massive

$$L_{n,eq,w} = 164 - 35 \cdot lgm' \quad \text{if} \quad m' \geq 100 \text{kg/m}^2$$
$$L_{n,eq,w} = 109{,}6 - 7{,}78 \cdot lgm' \quad \text{if} \quad m' \leq 100 \text{kg/m}^2 \qquad (3)$$

Raw floor: cross-laminated timber

$$L_{n,r,tv,0,w} = 98{,}5 - 7{,}78 \cdot lg\, m' \quad \text{if} \quad m' \leq 100 \text{kg/m}^2$$
$$L_{n,r,tv,0,w} = 153 - 35 \cdot lg\, m' \quad \text{if} \quad m' \geq 100 \text{kg/m}^2 \qquad (4)$$

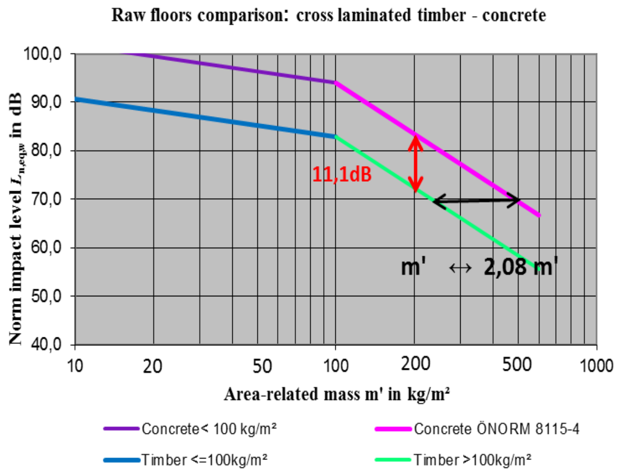

Figure 3: *Raw floors comparison*

The diagram (Figure 3) shows the norm impact level compared to cross laminated timber and massive concrete. We can see there is a greatly differing impact sound protection outcome between the two raw floors.
The diagram shows clearly that an 11,1 dB lower norm impact level can be achieved with cross laminated timber floors. However, realistically such high mass levels cannot be accomplished in timber floors. Likewise, the diagram indicates that at the same norm impact level, the timber floor mass would have to be about 2,08 times lower than in concrete floors.

Which sound insulation is ultimately achieved, depends on the combination of the structural element layers, the listed material properties and the thickness of the building elements. These points must be observed, if the desired impact sound protection levels according to OENORM or DIN building codes are to be achieved.

2.5 Wood-concrete composite floor

The raw floor consists of one layer of wood in the tensile area (thickness = 80 to 100 mm) and a concrete layer in the compression area (thickness = 60 to 120 mm). These two layers are combined with screws, bird mouths, tins, etc. in a force-locking manner. Both layers result in an area-related mass of m' = 180 to 320 kg/m². In terms of sound this floor behaves like a one-layer massive concrete floor of the same area-related mass. This floor structure provides a norm impact sound level of $L_{n,0,w}$ = 84 to 75 dB.

2.6 Timber beam floor

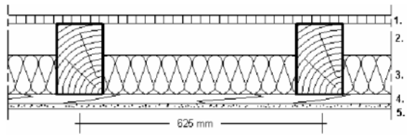

Figure 4: *Reference floor of ISO 140-11*

Light timber beam floors with flexible suspended ceiling (e.g. gypsum boards) have a weighted normalized impact sound level of $L_{n,r,0,w}$ = 72 dB. The frequency progression is favorable, similar to the reference curve, resulting in C_I = 0 dB. Sound protection improvement through mass increase between the beams or on the upper floor layer is recommended. The load capacity limits the potential improvement of airborne and impact sound protection. By doubling the mass a reduction of the norm impact sound level by 10 dB is achievable. This measure reduces the single number quantity down to about 60 dB (Figure 5).

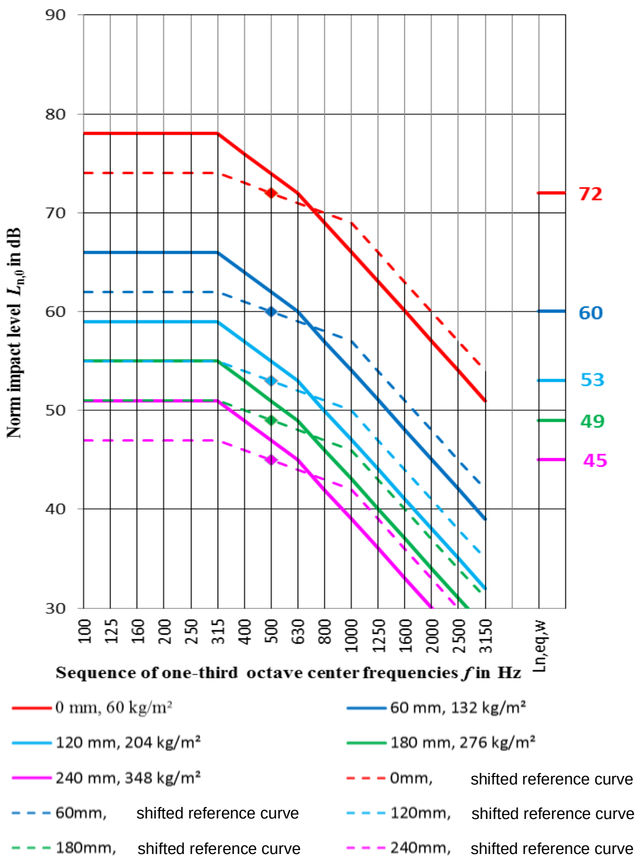

Figure 5: *Raw floor: 250 mm timber beam floor with additional weighting*

A comparison of the different floor types reveals that mass place a decisive role (most of all in the low sound range). It also shows that the mass factor in the floor structure does not lead to satisfactory static and economic results in terms of impact sound insulation.
The timber beam floor (2.6) which consists of a multi-layer structure shows that the impact sound levels in the

raw floor are better than in the two massive floors depicted (2.4 and 2.5).
The reason lies in its multi-layer properties. This in itself is not sufficient for adequate impact sound insulation if not enough mass is included.
Figure 5 shows the impact sound improvements that can be accomplished by combining mass to a multi-layered floor structure.
This model has come to be called Spring Mass System (Figure 6).
When combining the structural layers attention must be paid that the resonance frequency of the interacting individual layers lies below the building acoustic measuring threshold. This means for Austria below 100 Hz, and ideally in the range of about 80 Hz.

2.7 Floor structures and their properties

Model: Spring-Mass System

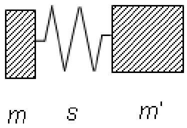

Figure 6: *Mass (m') – Spring (s') – Mass (m')*

Figure 7 reveals that the impact sound improvement above the resonance frequency increases considerably by 9 dB – 12 dB / octave. The useable frequency range is depicted.

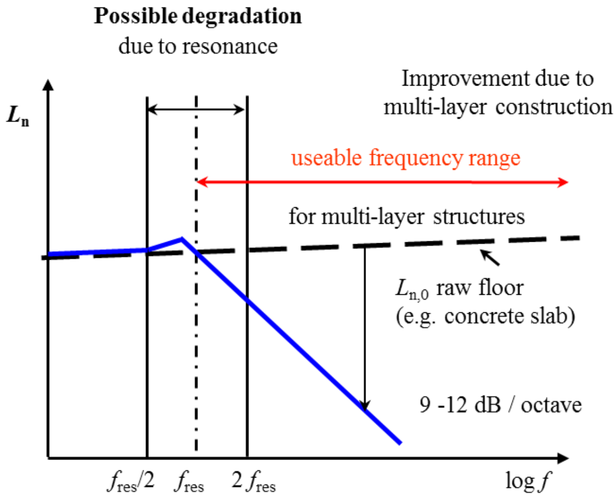

Figure 7: *Resonance frequency – multi-layer construction*

For the calculation of the resonance frequency in a mass – spring – mass system the following formula can be used.

$$f_{res} = \frac{1}{2\pi} \cdot \sqrt{s'\left(\frac{1}{m'_1} + \frac{1}{m'_2}\right)} \qquad (5)$$

s' = dynamic stiffness
m'₁, m'₂ = mass 1, mass 2

2.8 Floating screed on concrete slab

The improvement rates are dependent on the dynamic stiffness of the insulation layer and the mass of the floating screed.
The improvement values of the impact sound insulation shown in Figure 8 relate to a steel concrete slap.
For light structure systems such values are not available in building codes yet.

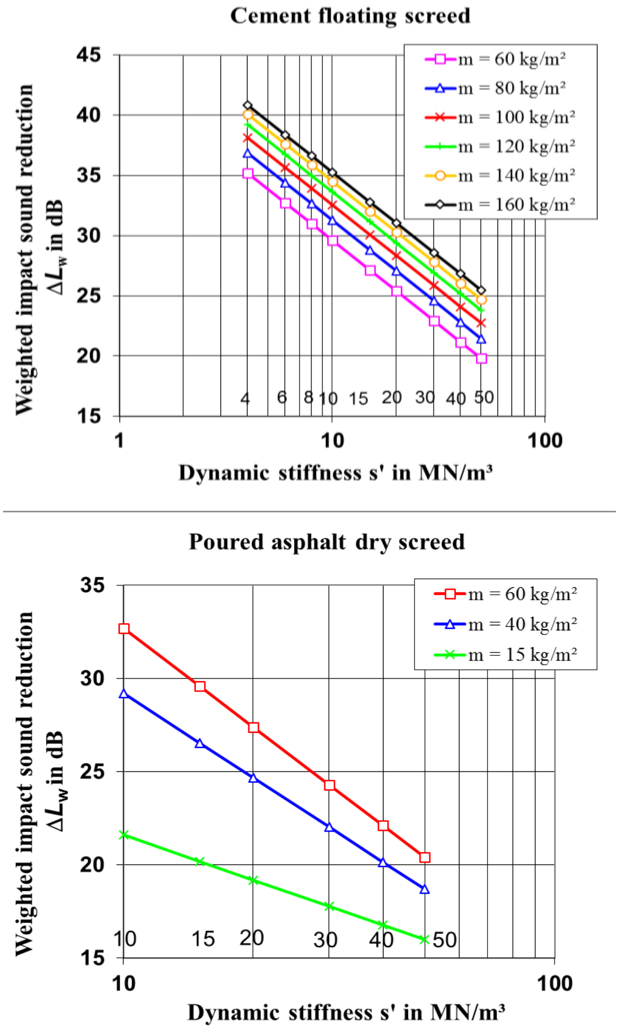

Figure 8: *Diagrams taken from OENORM B 8115-4*

Figure 9 shows the relationship between the dynamic stiffness and the thickness and type of insulation material. That means the choice of the optimal impact sound insulation board is a further essential criterion for achieving high impact sound protection values. The colored horizontal lines show the upper and lower limits and the ideal range between the two green lines that reflect the quality criteria applied in timber construction.

▬	Range for mineral wool sound impact protection boards CP 5 (types P and PS)
- - -	Range for mineral wool sound impact protection boards CP 2 (types PT)
○	Polystyrol sound impact protection boards (types EPS-T 350

Range for dynamics stiffness

Red line: Upper limit: stiffness

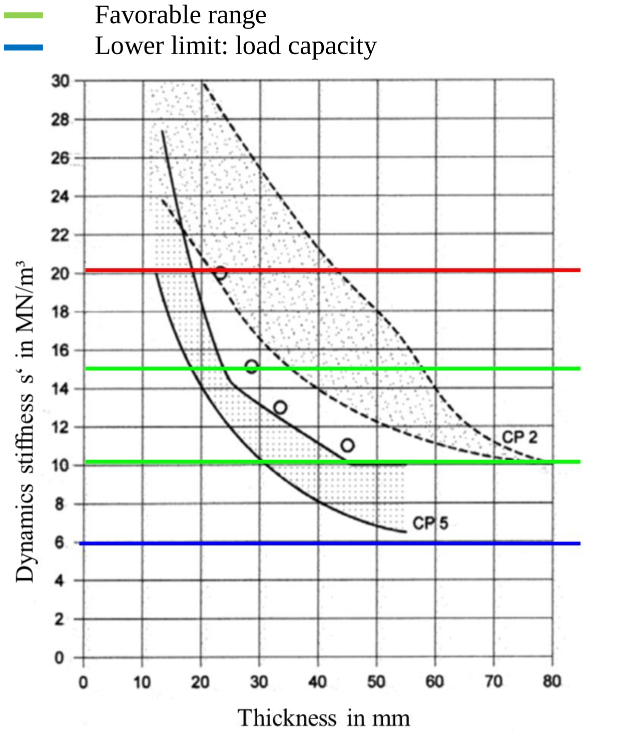

__Figure 9:__ Dynamic stiffness of insulation layer according to OENORM B 8115-4

2.9 Suspended ceilings and their properties

Up to their coincidence frequency of 2500 Hz elastic shells have a radiation efficiency of S = 10*log s ≤ 0 dB and they have therefore more favorable sound protection properties and are better suited for suspended ceilings. Elastic shells are, for example, gypsum boards (thickness ≤ 15 mm), wood-based boards (thickness ≤ 20 mm), and plywood boards (thickness ≤ 8 mm). The distance of ca. 50 mm to the lower end of the raw floor must be chosen such that the resonance frequency is $f_{res} \leq 80$ Hz. Additional dampening of the cavity with fiber insulation material is required. Improved sound protection values of the suspended ceiling depend on the area-related mass of the raw floor, the dynamic stiffness of the dampening and the area-related mass of the suspended shell.

__Table 1:__ Improvement index of impact sound protection due to suspended ceiling

Facing shell	Mass of heavy shell 100 kg/m²	Mass of heavy shell 400 kg/m²
Resonance frequency f_{res} in Hz	ΔL_{w} in dB	ΔL_{w} in dB
≤ 80	16	6
100	13	3
125	11	1
160	9	0
200	-1	-1
250	-3	-3
315	-5	-5
400	-7	-7
500	-9	-9
500 - 1600	-10	-10
> 1600	-5	-5

Improved values due to a suspended ceiling get smaller with increasing mass of the raw floor. The diagram shows the maximum improvement between 6 and 16 dB, if the resonance frequency is properly adjusted.

__Table 2:__ Overall impact of flanking transmission in massive and light constructions (OENOEM B 8115-4)

Area-related mass of floor in kg/m²	Correction factor K for flank transmission (in dB) at average-related mass of flanking structures in kg/m²								
	100	150	200	250	300	350	400	450	500
150	2	1	1	1	1	0	0	0	0
200	2	1	1	1	1	0	0	0	0
250	3	2	2	1	1	1	1	1	1
300	3	2	2	1	1	1	1	1	1
350	3	2	2	2	1	1	1	1	1
400	3	3	2	2	2	1	1	1	1
450	3	3	2	2	2	2	1	1	1
500	3	3	2	2	2	2	1	1	1
550	4	3	3	3	2	2	2	2	2
600	4	3	3	3	2	2	2	2	2

In massive construction and with common floors of ca. 400 kg/m² area-related mass and massive flanking structures of ca. 200 kg/m² the reduction of the impact sound protection due to flanking transmission amounts to 2 dB (EN ISO 12354-2).

2.10 Model of flanking transmission in timber construction DIN 4109 preliminary edition)

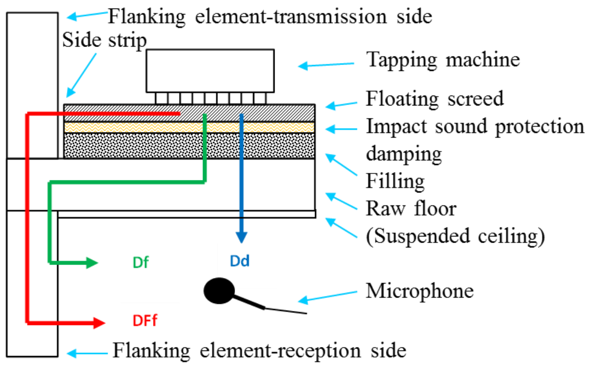

__Figure 10:__ Model of flanking transmission in timber construction Din 4109 (preliminary edition)

Transmission pathways

Dd Direct path (screed – raw floor) ⇒ $L_{n,w}$

Df Direct - flanking (screed – raw floor – reception side flank) ⇒ K_1 (1 – 6dB)

DFf Direct – flanking - flanking (screed – transmission side flank floor – reception side flank) ⇒ K_2 (0 – 7dB)

$$\boxed{L'_{n,w} = L_{n,w} + K_1 + K_2 \quad in\ dB} \qquad (6)$$

For 1 dB $\leq K_1 \leq$ 5 dB cross laminated timber floor without suspended ceiling or suspended one-layer gypsum board ceiling fixed on wooden frame or spring rails.

0dB $\leq K_2 \leq$ 1dB	if $L_{n,w} + K_1 \geq$ 55 dB
0dB $\leq K_2 \leq$ 2dB	if $L_{n,w} + K_1 \geq$ 48 dB
1dB $\leq K_2 \leq$ 5dB	if $L_{n,w} + K_1 \geq$ 43 dB

Far more complex is the flanking transmission mechanism in light structures. The reduction factors K1 and K2 - depending on the combination of structural elements – may vary in the range of 1 dB to 6 dB (K1) or 0 dB to 7 dB (K2) according to DIN 4109.

3 OBJECTIVES AND CONCLUSIONS

In the scientific investigation the focus was on finding out if improvement rates in multi-layered structures on wood concrete floors, cross laminated or glued laminated timber floors and timber beam floors are the same as in steel concrete floors. Moreover, the differences between the various raw floors was established.
A further objective of this scientific investigation was to provide a calculation tool that allows to determine the building code requirements of 48 dB in Austria (OENORM B 8115-2)

3.1 Improvement rates in different floor types

Impact sound reduction value (ΔL) in a multi-layer floor structure is dependent on the type of raw floor used!
Based on the steel-concrete slab (with or without filling) the weighted impact sound reduction ΔL_w due to a floating screed can be determined in Table 3.

Table 3: *Measurement results for impact sound protection improvement according to OENORM B 8115*

	Floor structure	$\Delta L_{t,w}$ Timber beam reference floor	$\Delta L_{tv,w}$ Glued laminated timber floor	ΔL_w Steel-concrete floor
1	19 mm particle board, ca. 13,3kg 20 mm mineral wool impact sound insulation board „ISOVER TDPT20/20“ ca. 118kg,m³, par gross density 115 kg/m³	7	18	25
2	two 19 mm particle boards, ca. 13,3kg each, glued laminated and screwed together 20 mm mineral wool impact sound insulation board „ISOVER TDPT20/20“ ca. 118kg,m³, par gross density 115kg/m³	7	16	24
3	20 mm gypsum board-dry screed elements 150 cm x 50 cm, ca. 23 kg/m² 20 mm mineral wool impact sound insulation board „ISOVER TDPT20/20“ ca. 118kg,m³, par gross density 115kg/m³	10	22	23
4	43 mm floating screed, ca. 2040 kg 0.2 mm PE-membrane 30 mm polystyrol impact sound insulation board „EPS-T 34/30“, ca. 16,6 kg/m³ 31 mm sand filling	20	22	28

The sound reduction is dependent on the area-related mass m’ of the screed and the dynamic stiffness s’ of the insulation layer. For the same floor structure of a glued laminated timber floor the weighted impact sound reduction $\Delta L_{tv,w}$ can be assessed.

$$\Delta L_{tv,w} = \Delta L_w - 7\ [\text{dB}] \qquad \geq 0\ \text{dB} \qquad (7)$$

For the same floor structure of a timber beam floor the weighted impact sound reduction $\Delta L_{t,w}$ can be assessed.

$$\Delta L_{t,w} = \Delta L_w - 18\ [\text{dB}] \qquad \geq 0\ \text{dB} \qquad (8)$$

Table 4: *Multi-layer floor construction on cross laminated or glued laminated timber floor to achieve $L_{nt,w}$ = 48 dB*

Construction layer	Material	Thickness [mm]	m‘ [kg/m²]	s‘[MN/m³]
Floating screed	cement, anhydrite	≥ 60	≥ 120	
Insulation layer	glass wool	≥ 20		≤10
	mineral wool	≥ 30		≤10
	wood fiber board (s‘ > 20 MN/m³)	-		not achievable
	EPS-T (s‘ > 12 MN/m³)	≥ 40		≤12 not recommended
	rubber granulate (s‘ > 15 MN/m³)	-	-	not achievable
Filling	gravel, grit	≥80	ϱ >1200kg/m³	-
Weighting	marble grit		ϱ >1400kg/m³	-
	polystyrene concrete	not achievable	-	-
Raw floor	cross laminated floor	≥ 120	≥ 54	-
Suspended ceiling required	attachment construction, mineral wool	≥ 50		-
	gypsum board, gypsum fiber board	≥ 15	≥ 12	-

Table 5: *Multi-layer floor construction on wood-concrete composite floor to achieve $L_{nt,w}$ = 48 dB*

Construction layer	Material	Thickness [mm]	m‘ [kg/m²]	s‘[MN/m³]
Floating screed	cement, anhydrite	≥ 50	≥ 120	
Insulation layer	glass wool, mineral wool	≥ 20		≤10
	wood fiber board	≥ 20		not achievable
	EPS-T	≥ 20		≤10
	rubber granulate (s‘>10 MN/m³)	-	-	not achievable
Filling	gravel, grit	≥80	ϱ >1200kg/m³	
Weighting	marble grit		ϱ >1400kg/m³	
	polystyrene concrete (ϱ >400kg/m³)	not achievable	-	-
Raw floor	concrete + (connecting device)	≥ 60	≥ 130	-
	glued laminated timber floor	≥ 120	≥ 54	
Suspended ceiling required	attachment construction, mineral wool	≥ 35		
	gypsum board, gypsum fiber board	≥ 15	≥ 12	

Table 6: *Multi-layer floor construction on timber beam floor to achieve $L_{nt,w}$ = 48 dB*

Construction layer	**Material**	**Thickness [mm]**	**m' [kg/m^2]**	**s'[MN/m^3]**
Floating screed	cement, anhydrite	≥ 60	≥ 120	
Insulation layer	glass wool	≥ 20		≤10
	mineral wool	≥ 30		≤10
	wood fiber board (s' > 20 MN/m^3)	not achievable		s' too high
	EPS-T (s' > 12 MN/m^3)	not achievable		s' too high
	rubber granulate (s' > 15 MN/m^3)	not achievable	-	s' too high
Filling	gravel, grit	≥80	ϱ >1000kg/m^3	-
Weighting	marble grit		ϱ >1400kg/m^3	-
	polystyrene concrete (ϱ >400kg/m^3)	not achievable	too light	-
Raw floor: standard-floor acc. ISO	timber beam floor	≥ 250	≥ 60	-
Integrated suspended ceiling	spring rails, mineral wool	≥ 50		

Table 7: *Multi-layer floor construction on steel concrete floor to achieve $L_{nt,w}$ = 48 dB*

Construction layer	**Material**	**Thickness [mm]**	**m' [kg/m^2]**	**s'[MN/m^3]**
Floating screed	cement, anhydrite	≥ 50	≥ 100	-
Insulation layer	Glass wool, mineral wool, EPS-T, wood fiber board, rubber granulate	≥ 20	-	≤ 30
Filling	gravel, grit	≥80	-	-
Weighting	polystyrene concrete	not required	-	
Raw floor	steel concrete	≥ 160	≥ 350	-
Suspended ceiling	not required			

Depending on the combination of the structural element layers, the listed material properties and the thickness of the building elements must be observed, if the desired impact sound protection levels according to ÖNORM or DIN building codes are to be achieved.

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