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ANALYSIS OF MEASURED TRANSMISSION FUNCTIONS IN TIMBER BUILDINGS

Fabian Schöpfer[1*] **Andreas Mayr**[1] **Ulrich Schanda**[1]
Jeremias Bayer[1]
[1] Rosenheim Technical University of Applied Sciences

ABSTRACT

To estimate machinery noise EN 12354-5 [1] provides methods for airborne and structure-borne sound transmission. For the latter the source and receiver mobility need to be considered. In the current revision a general case is described that allows any mobility ratio. This formulation uses the structure-borne sound power as input quantity for prediction to account for the coupling between source and receiver. The global transmission can therefore be described as the ratio between the spatial average sound pressure level in a room and the structure-borne sound power of the source connected to a building element and is defined in ISO 10848-1 [2] as level difference D_{TF}. This quantity can be calculated or measured. In case of a measurement each transmission situation seems to be unique in the first place. Nevertheless in previous work it was presented for timber buildings, that the spread of data can be reduced when grouping similar constructions and paths. In recent years data were continuously collected in field measurements. This paper presents the analysis of this data set with the aim to derive average values of groups that can be used for prediction.

Keywords: *machinery noise, structure-borne sound, timber buildings*

**Corresponding author: fabian.schopfer@th-rosenheim.de.*

1. DEFINITION OF TRANSMISSION FUNCTIONS AND PREDICTION METHOD

For the prediction of machinery noise in buildings a source term and a transmission term is required. This paper focuses on the transmission. Therefore the following standards are relevant. ISO 10848 describes measurement methods, and EN 12354-5 prediction methods. These measurement and prediction methods as well as all quantities that are relevant for structure-borne sound transmission are briefly introduced in this section.

In ISO 10848 D_{TF} is defined as the ratio, i. e. the level difference between the spatial average sound pressure level in a receiving room and the installed structure-borne sound power applied at an excitation point k.

$$D_{\mathrm{TF},k} = L_{\mathrm{av},k} - L_{W,k} \tag{1}$$

This can be measured and averaged for several excitation positions on a building element, i to give $D_{\mathrm{TF,av}}$. In addition the sound pressure level in the receiving room can be normalized to the absorption area to give $D_{\mathrm{TF,av,n}}$.

ISO 10848-1 describes normalized flanking sound pressure levels for impact sound $L_{\mathrm{n,f}}$ (i. e. excitation with the standard tapping machine) and for an equipment $L_{\mathrm{ne0,f}}$ (index e) with 1 W installed power (index 0, $L_{W0} = 120\,\mathrm{dB}$) [1]. The normalized flanking equipment sound pressure level $L_{\mathrm{ne0,f}}$ can be written using $D_{\mathrm{TF,av,n}}$ [2].

$$L_{\mathrm{ne0,f}} = D_{\mathrm{TF,av,n}} + L_{W0} \tag{2}$$

Following this notation, EN 12354-5 introduces the apparent normalized sound pressure level produced by a unit power structure-borne sound source connected at different positions on element i in the source room $L'_{\mathrm{ne,s,0},i}$

[1] If only one flanking path determines the sound transmission

(see also [3] with slightly different notation).

$$L'_{\mathrm{ne,s,0},i} = D_{\mathrm{TF,av,n}} + L_{W0} \quad (3)$$

This quantity includes all flanking paths involved in the transmission. Hence the level difference $D_{\mathrm{TF,av,n}}$ describes all transmission paths globally in this context [2].

For prediction, equation (3) can be rewritten for an unknown apparent normalized sound pressure level $L'_{\mathrm{ne,s},i}$

$$L'_{\mathrm{ne,s},i} = L'_{\mathrm{ne,s,0},i} + L_{W\mathrm{s},i} - L_{W0} \quad (4)$$

This power based formulation describes the transmission across the building due to structure-borne sound excitation from any source in general. Therefore this is also described as *general case* in prEN 12354-5:2022. Impact sound measured and predicted using the standard tapping machine can be considered as one particular case of structure-borne sound excitation.

However this requires knowledge about the installed structure-borne sound power of the considered source connected to element i. This is the major difference to the prediction of impact sound where only the building transmission is considered for one specific reference excitation (i. e. the standard tapping machine). To determine the required parameters of the source, EN 15657 [4] describes laboratory measurement methods.

This paper considers measured transmission functions in timber buildings. In the following measured transmission functions D_{TF} according to ISO 10848 [2] are presented according to equation (3) as $L'_{\mathrm{ne,s,0},i}$.

2. PREVIOUS WORK

In literature there are a couple of approaches to describe the transmission using transfer functions (e. g. [5, 6, 7, 8, 9, 10]). Within a national research project on machinery noise [11] the concept of using measured transfer functions was revisited. However the ratio between sound pressure and sound power consideres a general formulation and is in-line with the ISO 12354 series of prediction methods. The measurement protocols were developed [12] and first measurements were carried out in the laboratory and in the field. From these data-set the first approaches to group and categorize the data for prediction were developed. Case studies indicated the applicability of this approach [13]. This was pursued within another national project and the data set increased [14]. The work is still in progress, i. e. field measurements are continuously carried out. And the strategies for categorisation of the data are improved in parallel.

[2] n. b. This is similar to the normalized sound pressure level difference D_{n} for airborne sound.

3. MEASUREMENTS OF TRANSMISSION FUNCTIONS

Following the measurement protocols developed in [12] and standardised in ISO 10848, field measurements are carried out to collect data with the aim to derive an empirical prediction method based on categorised data. In particular for timber constructions it currently seems that this is the most practical approach that may find the way into practical application.

The measurements are carried out with the multi channel measurement system PAK by Müller-BBM VibroAkustik Systeme GmbH. This allows a parallel measurement of excitation and response. The building elements are excited with an impulse hammer. In [12] it was shown that for the constructions and force levels considered, this is equivalent to steady-state measurements with a shaker. As D_{TF} requires the power, two accelerometers are mounted close to the excitation point. In parallel the sound pressure is measured in the considered receiving room with six microphones in parallel. With this setup data can be measured time-efficient on-site where only small time windows are possible in the schedule of a building project. In addition the reverberation time is measured in the receiving room to normalise or standardise the data. On typical surfaces in timber buildings (gypsum board, timber, or similar) it is not possible to inject a force spectrum towards the upper end of the building acoustics frequency range. In addition with the high attenuation in the transmission towards high frequencies in timber buildings, measurements in the field are normally only possible up to about 2 kHz in maximum. Towards low frequencies data are processed down to the 20 Hz one-third octave band. However below 50 Hz no normalisation or standardisation is applied and the frequency range is highlighted in the figures. Nevertheless it is shown to give an idea about the spectrum in this frequency range as this may be of particular interest for machinery noise.

Up to now data is available from measurements in 27 individual timber buildings with about 185 transmission functions. In each building various transmission situations are considered, depending on the floor plan, the construction type and the accessibility. In general typical situations relevant for machinery noise or noise from service equipment are preferred for measurements. These may be diagonally adjacent rooms between two apartments where the source room (i. e. the walls and floors) can be a bathroom or a utility room. In general situations with similar floor plans in each storey are preferred to avoid offsets in wall-floor junctions as these would be data-sets that can hardly be associated to groups.

4. CONCEPT TO FIND GROUPS

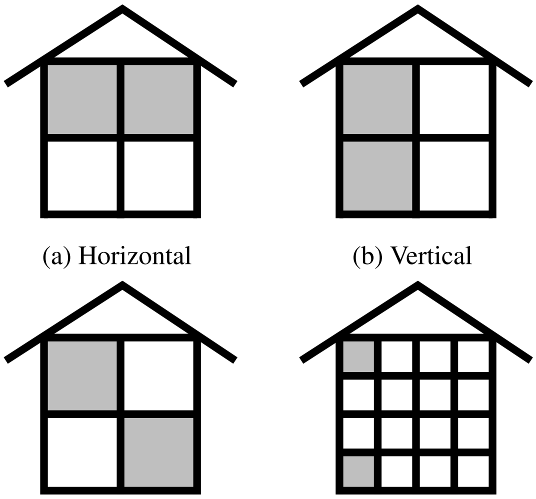
Each transfer function or transmission function D_{TF} is unique for the considered situation. However the previous work both from research in Rosenheim and other authors already showed that there are similarities in the data for groups with similar parameters. This is the motivation to derive groups from the measured data. The difficulty is however to find a suitable number and type of parameters to group the data as there is a conflict of interest. For a practical application it is not possible to require a huge amount of detailed information on the whole transmission, e. g. number of screws or particular type of sheathing plates. But a certain degree of detail is required to reduce the variation of the data within the groups as this is directly linked to the uncertainty in prediction.

Based on this the following criteria are used to group the data: (a) separate apartment/unit, (b) spatial separation of rooms, (c) type of excited building element and (d) most relevant element construction. These criteria are explained in more detail in the following:

(a) separate apartment/unit: The measured data set comprises measurements in detached houses, semi-detached houses, apartment buildings and office buildings. For all these building types the transmission was measured within a unit or across residential units. Although there are usually no requirements on noise within a unit, these paths can be interesting for manufacturers to increase the acoustic quality of their houses. Processing of the data showed, that this first criterion separates the data because typically the preferred constructions for a separation in semi-detached houses and apartment buildings have a good sound insulation.

(b) spatial separation of rooms: This criterion describes the location of the source room, i. e. the room that contains the excited building element, relative to the considered receiving room. Figure 1 shows four examples for this criterion.

(c) type of excited building element: For each of these separations of rooms different building elements in the source room can be excited. It is obvious that this has

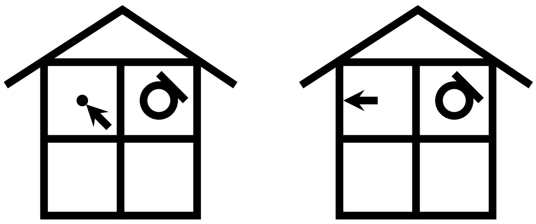


(a) Horizontal (b) Vertical

(c) Vertical offset (d) Vertical two rooms

Figure 1: Examples for criterion (b) spatial separation of rooms.

a significant influence on the transmission function. The following types of excited building elements are considered: Interior wall, separating wall (between apartments), party wall (between semi-detached houses), exterior wall and floor. The combination of criteria spatial separation of rooms and type of excited building element might not be unique. Figure shows an example. However in the cur-



(a) First order flanking exterior wall (b) Second order exterior wall

Figure 2: Examples showing that the combination criteria spatial separation of rooms and type of excited building element might not be unique.

rent data set none of these situations occurs. Typically the building elements closer to the receiving room were excited.

(d) most relevant element construction: Typically this criterion is related to the excited building element. Therefore typical construction types in timber buildings are considered. For separating walls this could be for example: Single framework with lining, Cross-laminated-timber (CLT) wall with lining, separated framework or separated framework with lining. However if the transmission is across a floor and the excited building element is a wall the existing data showed that the construction of the floor is more important in this case.

5. ANALYSIS OF DATA

Using the criteria mentioned above the data was categorised. By sequentially picking individual features of these criteria single groups can be filtered. It is therefore also possible to filter using only 3 out of 4 criteria. In the following some examples are presented.

Figure 3 shows the filtered data set for (a) separated residential units, (b) vertically adjacent rooms, (c) separating wall (between appartments) and all features available in the data set for (d).

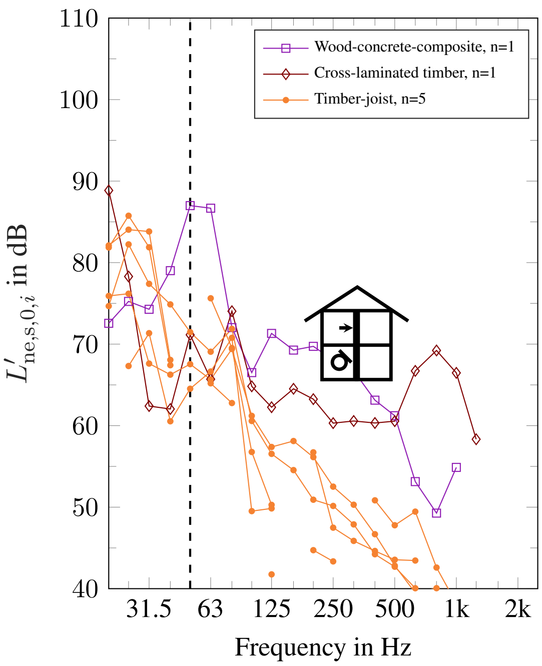


Figure 3: Excitation of separating wall for vertically adjacent rooms between different residential units. All kinds of separating floor constructions in the available data-set.

It can be seen that the five data-sets with timber-joist separating floors form a group with a similar spectral characteristic that significantly deviates from the data sets for the other two floor types. The five data-sets for the timber joist floors are from different buildings with different construction types of both the separating wall and the timber joist floors. Although there is no information given on the construction details the filtered data for this group obviously shows the same spectral characteristic. The four criteria (a) to (d) were applied to the full data-set available where the same findings could be observed [15].

For each unique combination of these four criteria the median was considered as representative spectrum for this group. To give an indication on the spread of the data the standard deviation is used. The sample size is very small an therefore the standard deviation can not be considered as robust estimate for the variation, however it gives a solid indication on the spread of data. This is shown as an example in Figure 4 for the group of timber-joist floors from Figure 3. The spread of the data is up to 5 dB above

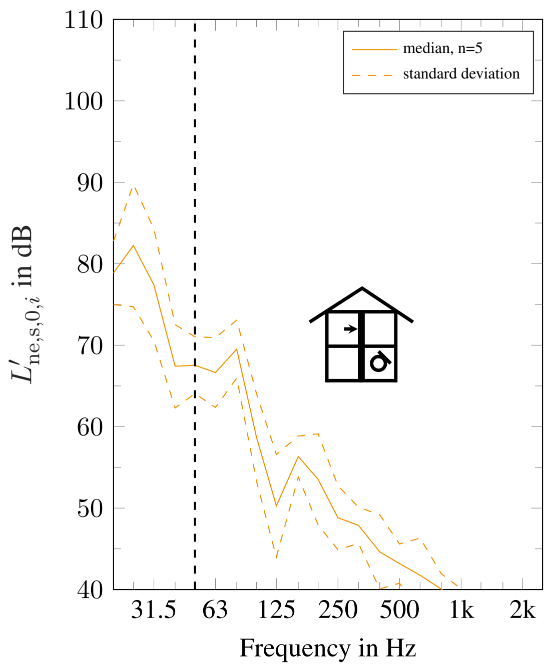


Figure 4: Median and standard deviation for vertical adjacent rooms, excited separating wall and timber-joist floor.

200 Hz and up to 8 dB below 200 Hz. However it must be considered, that only the rough criteria described above

were used to form this group and the data is from randomly different buildings from different manufacturers.

From the analysis of the data and the application of these criteria it was observed that spread of data increases with decreasing length of the global transmission path. This is shown for the following criteria as an example: (a) same residential unit, (b) horizontally adjacent rooms, (c) interior wall excited and (d) single-frame construction with lining. The filtered group is shown in Figure 5. Again

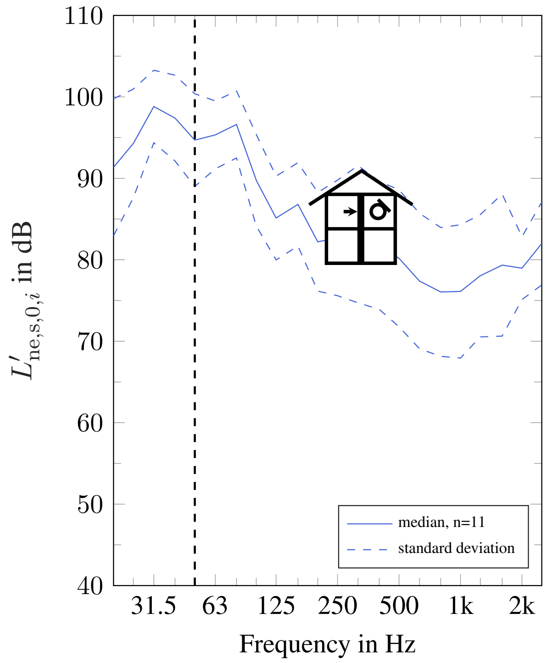


Figure 5: Median and standard deviation for horizontally adjacent rooms, with a single frame interior wall with lining.

the median in combination with the standard deviation is shown for the filtered group that has a sample size of eleven. The spread of data is higher compared to Figure 4 in particular in the mid and high frequency range.

6. SUMMARY AND OUTLOOK

The analysis of the currently available data-set of measured transmission functions indicates that it is feasible to form groups with similar spectral characteristics and small spread of data with four simple parameters to filter the data. This is promising when the goal is to develop a practical prediction method based on categorised data.

The chosen criteria can be practically applied by the consultant because only little knowledge of the actual construction details is required. Three criteria (a-c) describe the path between the excited building element and the receiving room. A fourth criteria is introduced to account for the construction type of the relevant building element which might be the excited wall or the floor if the transmission is across a storey. From these four criteria a catalogue of the existing data can be created that can be easily applied in building acoustic consultancy.

Although the findings indicate the practical applicability it is still required to collect and analyse more data. It is essentially required to provide a robust estimate for the uncertainty of this method which is currently not possible.

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8. REFERENCES

[1] prEN 12354-5:2022, “Building acoustics - estimation of acoustic performance of buildings from the performance of elements - part 5: Sounds levels due to the service equipment.”

[2] ISO 10848-1:2017, “Acoustics – laboratory and field measurement of flanking transmission for airborne, impact and building service equipment sound between adjoining rooms: Part 1: Frame document.”

[3] M. Villot, “Predicting sound levels generated on site by structure-borne sound sources in buildings,” in *Proceedings of Euronoise 2018*, 2018.

[4] EN 15657:2017, “Acoustic properties of building elements and of buildings - laboratory measurement of structure-borne sound from building service equipment for all installation conditions.”

[5] H. F. Steenhoek and T. Ten Wolde, “The reciprocal mesurement of mechanical-acoustical transfer functions,” *Acustica*, vol. 23, pp. 301–305, 1970.

[6] K. J. Buhlert and J. Feldmann, “Ein meßverfahren zur bestimmung von körperschallanregung und -übertragung,” *Acustica*, vol. 42, no. 3, pp. 108–113, 1979.

[7] M. L. S. Vercammen and P. H. Heringa, “Characterising structure-borne sound from domestic appliances,” *Applied acoustics. Acoustique applique. Angewandte Akustik*, vol. 28, pp. 105–117, 1989.

[8] H.-M. Fischer, “Determination and use of transfer functions to describe structure-borne sound transmission caused by equipment and installations,” in *Proceedings of ICA 2001*, 2001.

[9] W. Scholl, “About a test facility for installation noise in wooden houses,” in *Proceedings of Forum Acusticum 2005*, pp. 1977–1981, 2005.

[10] J. Arnold and O. Kornadt, “Beschreibung körperschallinduzierter schalldruckpegel mit hilfe von übertragungsfunktionen,” in *Bauphysik Kalender 2014* (N. A. Fouad, ed.), pp. 641–663, D-69451 Weinheim, Germany: Wiley-VCH Verlag, 2014.

[11] U. Schanda, A. R. Mayr, and F. Schöpfer, “Fhprofunt 2012: Nachhaltiger schallschutz gebäudetechnischer anlagen in energetisch optimierten gebäuden: Teilprojekt 2: Schlussbericht.”

[12] F. Schöpfer, C. Hopkins, A. R. Mayr, and U. Schanda, “Measurement of transmission functions in lightweight buildings for the prediction of structure-borne sound transmission from machinery,” *Acta Acustica united with Acustica*, no. 103, pp. 451–464, 2017.

[13] F. Schöpfer, C. Hopkins, A. R. Mayr, and U. Schanda, “Prediction of noise from machinery in timber-frame buildings using transmission functions,” in *Proceedings of ICSV24*, 2017.

[14] F. Schöpfer, A. R. Mayr, and U. Schanda, “Structure-borne sound sources in timber buildings – prediction of machinery noise using measured transmission functions,” in *Proceedings of ICA 2019*, 2019.

[15] J. Bayer, *Übertragungsfunktionen zur Prognose von Geräuschen aus gebäudetechnischen Anlagen: von der Messung bis zur normativen Verwendung*. Masterarbeit, Technische Hochschule Rosenheim, 2022.