Structure-borne sound sources in timber buildings – prediction of machinery noise using measured transmission functions

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Abstract

Prediction of machinery noise in buildings involves two stages: (a) the emission of structure-borne sound and (b) the transmission (i.e. the propagation) across the building structure. This paper concerns the latter in timber buildings. In previous work a practical approach to predict the equipment sound pressure level using measured transmission functions was presented. A research project conducted at the Technical University of Applied Sciences Rosenheim pursued this approach by measuring a range of transmission functions in various timber buildings. In total a data set of 120 transmission functions measured in 19 timber buildings is now available. This paper gives a survey of this data by grouping similar constructions and transmission paths. The approach can be used to derive average transmission functions for similar situations. Those could potentially be provided in a catalogue giving data in one-third-octave bands. The application of this empirical prediction method is presented in a case study using a fictive structure-borne sound source in timber buildings.

Keywords: Building noise control; structure-borne sound sources; lightweight buildings

1 INTRODUCTION

To proof the requirements on sound insulation in residential buildings, prediction of sound emission from machinery and service equipment is required. EN 12354-5:2009 [1] provides a method for prediction in heavyweight buildings. However there are no validated prediction tools for lightweight timber constructions that gained increasing attention in recent years. Hence it is only possible to proof the requirements on sound insulation using measurements in the actual building. To-date the design of constructions and choice of equipment in terms of machinery noise is based on previous project experience. This leads to oversized constructions that can be unattractive in terms of the costs. EN 12354-5:2009 is currently under revision to include lightweight constructions. In previous papers [2, 3] an empirical method was proposed that is based on a data-set of measured transmission functions. This paper presents the results of a research project at the Technical University of Applied Sciences Rosenheim that took the definition of transmission function [3] to collect data in field measurements. The presented results add on to the data presented in [4]. From this data-set representative transmission functions for similar constructions and paths are derived that can be used to estimate the sound pressure level from service equipment.

2 DEFINITION OF TRANSMISSION FUNCTION

The transmission function D_{TF} is defined as follows [3, 5].

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

$L_{\mathrm{W},k}$ is the input structure-borne sound power level at an excitation position, k, and $L_{\mathrm{av},k}$ is the resulting spatial average sound pressure level in a receiving room. This transmission function can be spatially averaged for K excitation positions to give an average transmission function, $D_{\mathrm{TF,av}}$, by

$$D_{\mathrm{TF,av}} = 10\lg\left(\frac{\sum_{k=1}^{K} 10^{0.1 D_{\mathrm{TF},k}}}{K}\right) \tag{2}$$

The standardized spatial-average transmission function, $D_{TF,av,nT}$ is

$$D_{TF,av,nT} = D_{TF,av} - 10\lg\left(\frac{T}{T_0}\right) \tag{3}$$

where T is the reverberation time in the receiving room and T_0 is the reference reverberation time of 0.5 s. To determine the spatial average sound pressure level at low frequencies the procedure for field measurements of sound insulation [6] is applied as described in [3].

3 FIELD MEASUREMENTS

The main aim of the research project 'Übertragungsfunktionen im Holzbau' (Transmission functions in timber buildings) was to increase the data-set on measured transmission functions in timber constructions. So far measurements are available from 19 buildings including timber-frame constructions as well as constructions using CLT (Cross-Laminated-Timber) elements. As usually more than one transmission path was considered in each building, the data-set contains 120 transmission functions. For each situation at least two excitation positions were averaged although the range of different excitation positions is typically within ±4 dB [3] even for timber-frame constructions. Each of these measured transmission functions is unique for the specific situation. Hence representative spectra were derived to estimate the sound pressure level from machinery for similiar situations. For this purpose groups were defined based on the following criteria:

Transmission path: This criterion describes the path from the excited building element to the considered receiving room. Direct transmission can be across a separating wall i. e. across a separating floor. Vertical transmission describes basically the flanking path for an excited wall to the room above or the below the room where the excitation took place. Similarly diagonal transmission considers the transmission to the room diagonally above or below the room where the excitation took place. In addition to these examples other transmission paths were defined from the exciting data-set to give in total 18 different transmission paths. These include also transmission across two or more junctions.

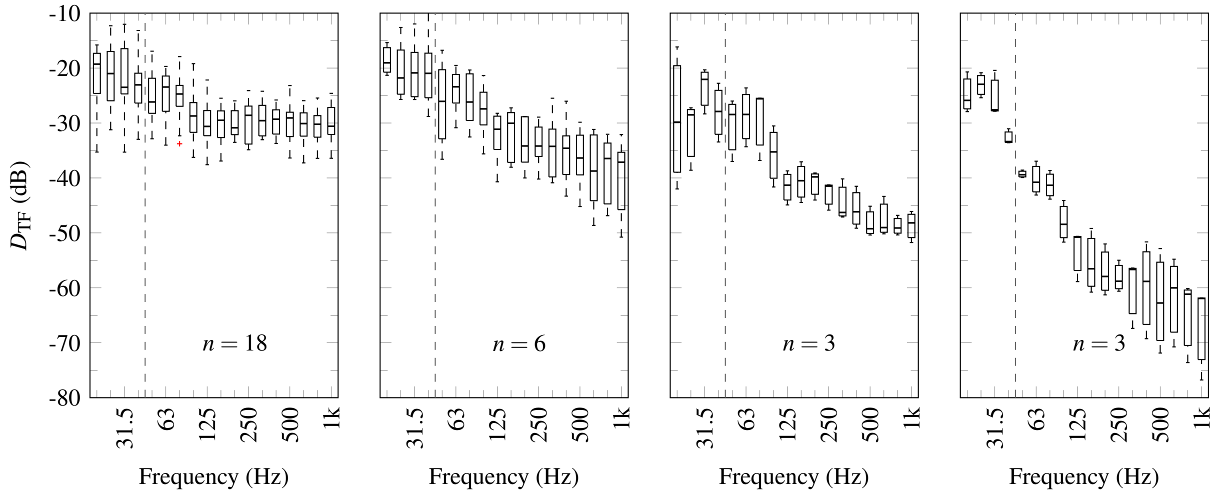
Type of excited building element: This criterion considers the purpose of the excited building element. This can be an interior wall within a flat, a separating wall, a party wall or an exterior wall for example. In total seven different building elements are available from the measured data-set.

Construction of excited building element: As measurements were carried in timber buildings the constructions comprise mainly timber-frame walls, timber-joist floor or wall and floors built with CLT elements. However measurements were also carried with excitation in the basement on the concrete or masonry walls. In total nine different constructions are available from the field measurements.

Additional layers: This can be a floating screed or a facing or facing in front of the base element of the excited wall or floor. It is distinguished between facings made from timber-frame constructions or using sanitary systems with metal channels. Different types of floating screed were also considered.

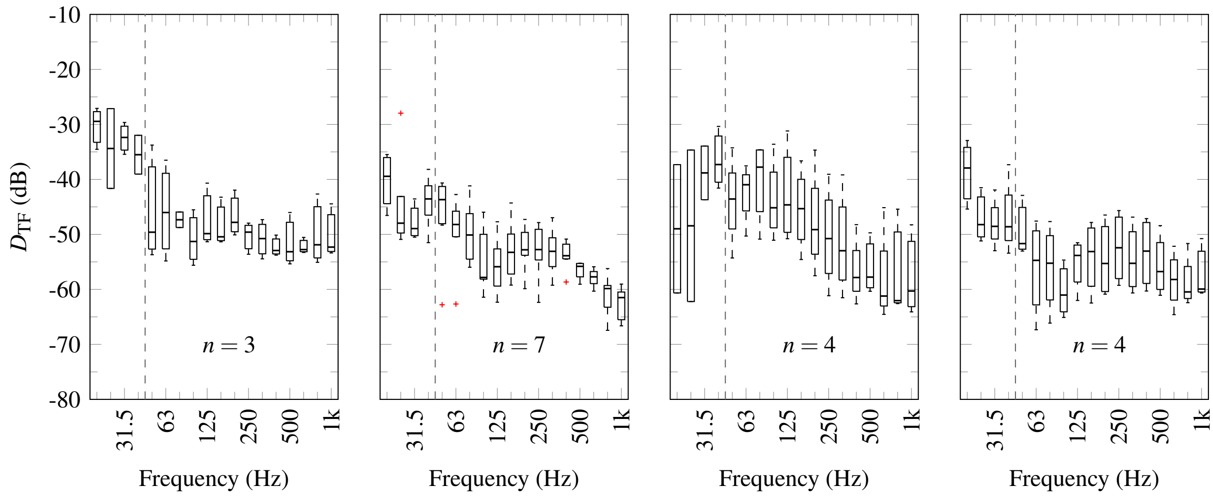
Using these criteria, groups were formed that contain measured data for which all four criteria are the same. From the data-set of 120 transmission functions 51 unique groups could be formed. However in some of the groups only one measured transmission function is available so far. In the following, the results for groups with at least three data-sets are presented. These 13 groups are presented as boxplots to give an indication on the range within the groups. The data is presented in one-third octave bands for the frequency range from 20 Hz to 1000 Hz. From 20 Hz to 40 Hz, $D_{TF,av,nT}$ is shown as the reverberation time was not available for all data-sets. At and above the 50 Hz one-third octave band, $D_{TF,av,nT}$ is shown (see dashed line in Figures 1 to 4).

Figure 1 shows four groups for horizontal transmission across different types of walls. Figure 2 shows four groups for vertical transmission (i. e. excitation of flanking wall) for different types of excited walls. Figure 3 shows three groups for diagonal transmission were cross-juntions and junctions with off-set are considered. Figure 4 shows two groups that describe the transmission from the excitation in the basement to a rooms in the ground floor or first floor with timber constructions.



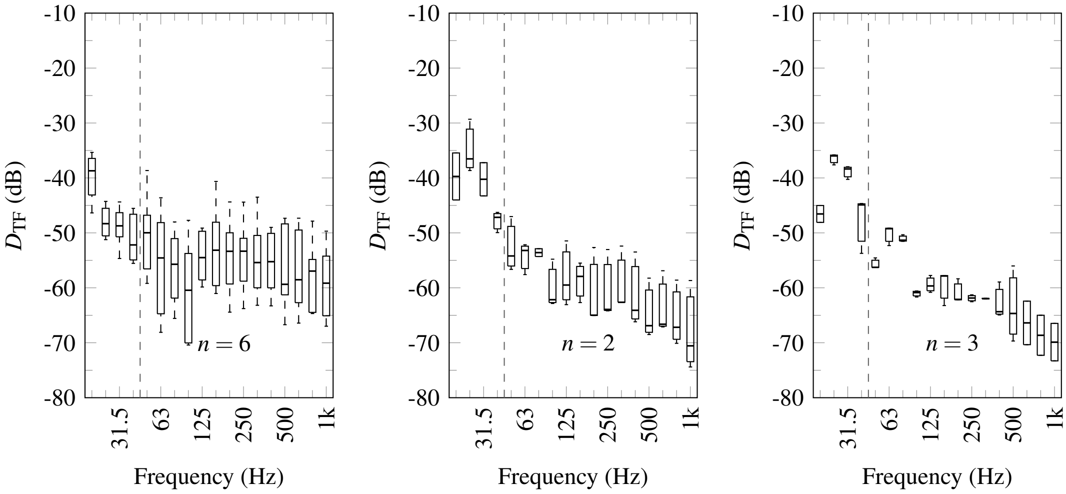
(a) (b) (c) (d)

Figure 1. Transmission path: horizontal/direct
(a) Single framework wall without additional facing, (b) Single framework wall with facing for pipes (also timber-frame construction), (c) Single framework wall with additional layer made from laths or resilient channels perpendicular to the wall studs, (d) Party wall, separated framework



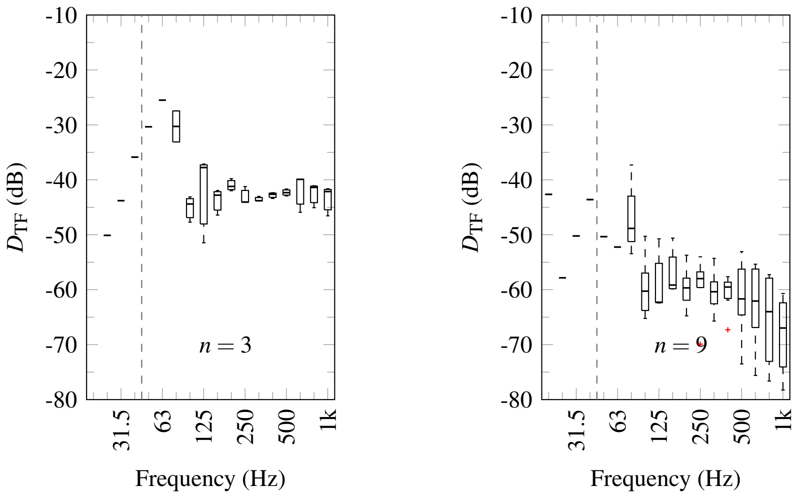
(a) (b) (c) (d)

Figure 2. Transmission path: vertical
(a) Exterior wall (T-junction), timber-frame construction, no facing, (b) Exterior wall (T-junction), timber-frame construction, facing for electric installations, (c) Exterior wall (T-junction), CLT (Cross-Laminated-Timber), no facing, (d) Interior wall (cross-junction), timber-frame construction, no facing



(a) (b) (c)

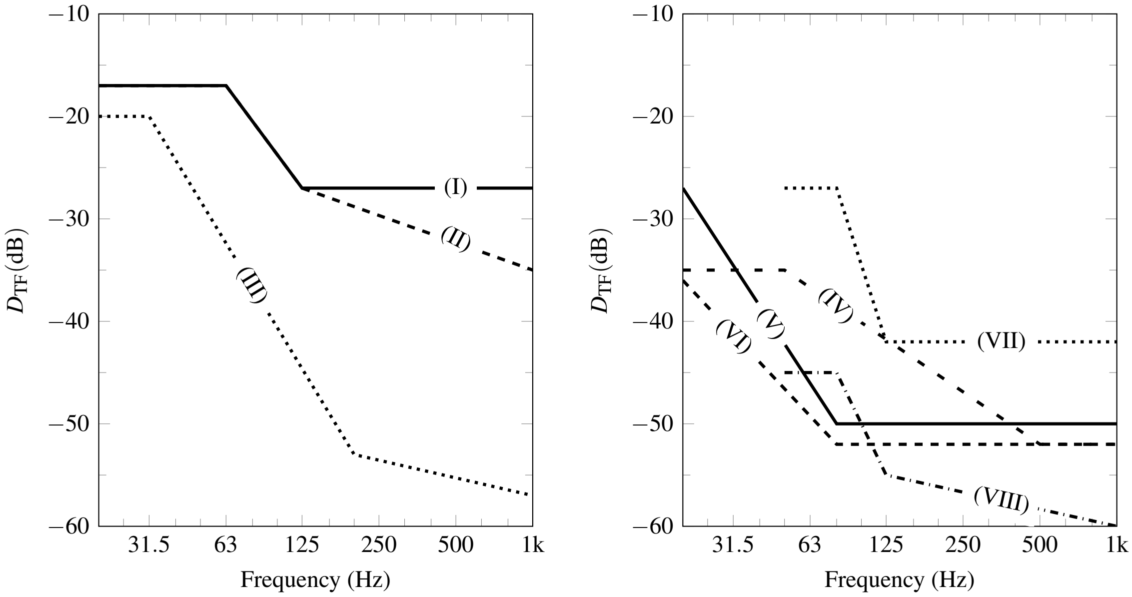
Figure 3. Transmission path: diagonal
(a) Cross-junction, timber-frame construction, no facing, (b) Cross junction with offset, timber-frame construction, no facing, (c) Cross junction with offset, timber-frame construction, with facing



(a) Basement to ground floor (b) Basement to first floor

Figure 4. Transmission path: Vertical from the basement to the ground floor or first floor with timber construction.

From the data shown in Figures 1 to 4, representative spectra were derived that follow the 75 % quantile (i. e. the upper bound of the boxes) of the data within each group. Figure 5 shows eight representative spectra for transmission within a storey or across one or more junctions. For group (VII) and (VIII) there was insufficient singal-to-noise ratio for most measurements below 50 Hz and therefore the reprentative spectra are available for one-third octave bands at and above 50 Hz. These representative transmission functions indicate that there is a typical spectral shape for each of the groups.



(a) Direct transmission:
(I) see Figure 1a
(II) see Figure 1b
(III) see Figure 1c

(b) Transmission across one or more junctions:
(IV) see Figure 2c
(V) see Figure 2a
(VI) see Figure 3a
(VII) see Figure 4a
(VIII) see Figure 4b

Figure 5. Representative transmission functions.

4 APPLICATION

To show the application of the proposed empirical method, this section uses the representative transmission functions to estimate the sound pressure for a fictive structure-borne sound source that is fictively installed in each of the representative situations. This source was introduced and described in [4], where timber-frame and concrete receiving structures were considered. For the source and receiver mobility a constant value is assumed. For the source this value is in the order of magnitude of a compact wall-hanging ventilation unit that was investigated earlier [7]. The value for the receiver structures is in the order of magnitude of the infinte plate mobilities for a concrete wall, a CLT wall and a timber frame wall. The activity of the source is based on experience from investigations on source characterization. Scheck et al. [8] showed for various sources, that the power input from typically drops significantly with frequency. Figure 6 shows the installed power of this fictive source installed on three receiving structures which occur in the representative transmission functions shown in Figure 5.

Using the installed power and the representative transmission functions, the sound pressure level for this fictive source can be calculated for the eight presented representative situations. The results are shown as A-weighted sound pressure levels in Figure 7. However it has to be noted that focus should not be on the absolute value of the sound pressure level because a fictive source was considered. Hence the A-weighted sum in the figure caption is shown normalized to group (I) for the groups (II) to (VI) and normalized to group (VII) for group (VIII). The A-weighted sum was determined from 20 Hz to 1000 Hz for groups (I) to (VI) and from 50 Hz to 1000 Hz for groups (VII) and (VIII).

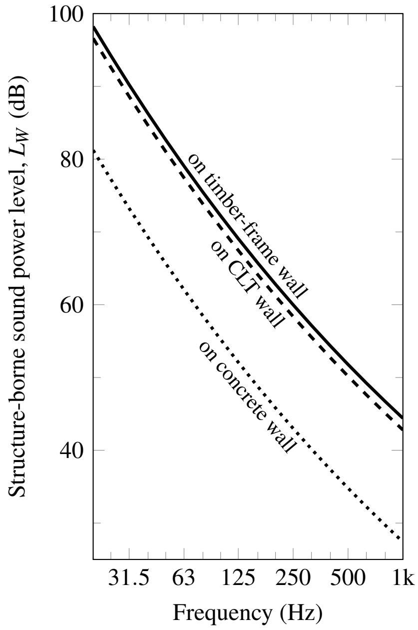
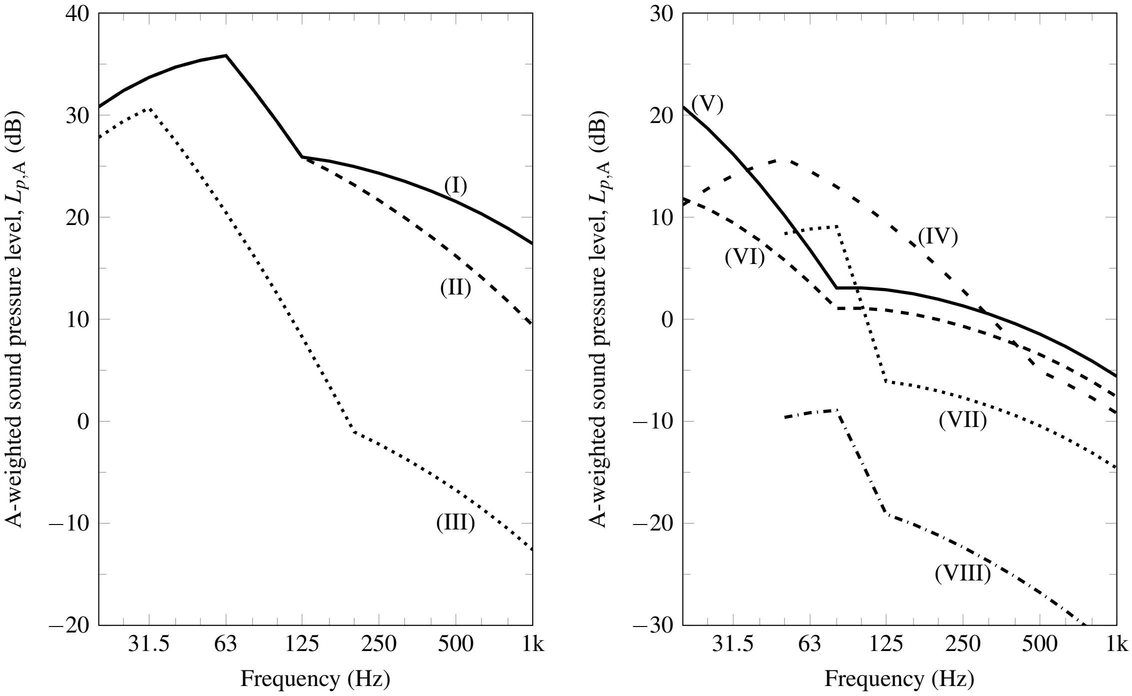


Figure 6. Installed structure-borne sound power level, $L_{W,\text{inst}}$, of a fictive source [4], fictivly attached to three receiving structures.

The sound pressure levels indicate the spectral shape for the same source attached in different situations. It can be seen that the A-weighted sum does not differ for direct transmission across an interior wall with or without an additional facing as the strength of the source is at low frequencies. Similarly the the sum is only 7 dB lower for a party wall with separated framework although this construction provides a major improvement towards high frequencies. For vertical transmission, the spectral shape differs for timber-frame walls or CLT walls but the A-weighted sum is very similar (2 dB difference). Compared to horizontal transmission, the A-weighted sum of the sound pressure level for vertical transmission is ≈20 dB lower. For diagonal transmission it is ≈25 dB lower. Similar observations can be made for the transmission from the basement to the ground floor compared to the transmission to the first floor. Adding one junction (storey) int he transmission path, the sum of the sound pressure level reduces by 17 dB. Interestingly the sound pressure level for transmission from the basement to the ground floor is in the same range compared to vertical or diagonal transmission in purely timber constructions <125 Hz, although the installed power is significantly lower. This is because the same power is transmitted more effectively from the heavy basement wall to the light timber construction (see Figure 5).

5 SUMMARY

This paper presented some of the results from a field survey of measured transmission functions. In total 120 transmission functions, measured in 19 timber buildings are available to-date. The proposed empirical approach for prediction suggests to form representative transmission functions for similar situations from measured data. Therefore the data was grouped based on the transmission path, the type and the construction of the excited building element as well the type of an optional additional layer like a floating screed. From these groups representative spectra were derived. In an example using a fictive source, which was fictivly installed in these situations, the sound pressure level was calculated. This allows to get insight into the expected sound pressure for the same source in various transmission situations.



(a) Direct transmission:
(I) $L_{p,\mathrm{A,sum}} = 43\,\mathrm{dB(A)}$ (20 kHz to 1 kHz)
(II) 0 dB normalized to (I)
(III) −7 dB normalized to (I)

(b) Transmission across one ore more storeys:
(IV) −20 dB normalized to (I)
(V) −18 dB normalized to (I)
(VI) −25 dB normalized to (I)
(VII) $L_{p,\mathrm{A,sum}} = 14\,\mathrm{dB(A)}$ (50 kHz to 1 kHz)
(VIII) −17 dB normalized to (VII)

Figure 7. A-weighted sound pressure level for the fictive source installed in situations from Figure 5.

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