# Predicting sound levels generated on site by structure-borne sound sources in buildings

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**Summary**

A method predicting sound levels generated on site by structure-borne sound sources in buildings, and valid for any source-receiver conditions and for any type of construction, lightweight or heavyweight, is being standardized within CEN TC126 WG2; the standard will be published, probably in 2019 as new version of EN 12354-5. Predictions are made from new power-based input quantities defined in the newly revised measurement standards EN 15657 (Laboratory characterization of service equipment) and EN ISO 10848-1 (Laboratory and field measurement of flanking transmissions). This paper explains the different approaches used, which depend on the source-receiver conditions and the type of construction, and describes the new quantities defined for characterizing sources and receivers (building elements) when dealing with service equipment. The potential advantages of this power-based method are then briefly discussed.

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## 1. Introduction

A method predicting sound levels generated on site by structure-borne sound sources in buildings, and valid for any source-receiver conditions and for any type of construction, lightweight or heavyweight (respectively type B or type A according to EN 12354-1 [1]), is being standardized within CEN TC126 WG2; the standard will be published, probably in 2019 as new version of EN 12354-5 [2]. Predictions are made from new power-based input quantities defined in the newly revised measurement standards EN 15657 [3] (Laboratory characterization of service equipment) and EN ISO 10848-1[4] (Laboratory and field measurement of flanking transmissions). The calculation models used have already been briefly described in a Short Communication [5]. This paper presents a more detailed description of the different prediction approaches used, which depend on the source-receiver conditions and the type of construction, and use new quantities for characterizing sources and receivers (building elements). The potential advantages of this power-based method are then briefly discussed.

## 2. Calculation models

### 2.1. General

The key input parameter for predicting sound levels generated on site by structure-borne sound sources in buildings is the source installed power (structural power injected to the receiving element), which depends on both source and receiver. Standard EN 15657 indicates how to calculate this installed power from the source and receiver relevant dynamic characteristics. The source is characterized by three quantities: free velocity, blocked force and mobility; any of them can be deduced from the other two. And the receiver is characterized by its mobility.

Two cases can be considered separately, leading to two different approaches for prediction: the simple case where the receiver mobility is much lower than the source mobility (common case of heavy building elements), in which only one source characteristic (the blocked force) is required, and the general case applicable to lightweight receiving elements in particular.

### 2.2. Case of low mobility building elements

Predicting equipment sound levels in the case where the receiver mobility is much lower than the source mobility is very specific. This case corresponds to a factor of about 10 between source and receiver mobilities, which is likely to be obtained with common service equipment mounted on concrete elements about 10 cm thick, or thicker. The installed power determination formula reduces with only one source characteristic required: the blocked force, expressed as single equivalent blocked force level $L_{\text{Fb,e}}$, which is defined and its measurement described in EN 15657.

The ISO tapping machine can as well be characterized by its blocked force level $L_{\text{Fb,tap}}$ , which can be easily calculated theoretically [6]. This similarity naturally leads to using the method defined in EN 12354-2 [7] (impact noise prediction) for predicting service equipment noise in situ. The structure-borne sound level $L_{\text{n,s}}$ generated in situ by any equipment connected to an heavy floor or wall can be estimated from the corresponding in situ impact sound $L_{\text{n}}$ of the floor or wall, calculated using EN 12354-2, and corrected for the difference in blocked force level between equipment and tapping machine according to

$$L_{\text{n,s}} = L_{\text{n}} + L_{\text{Fb,e}} - L_{\text{Fb,tap}}, \qquad (1)$$

where $L_{\text{n}}$ is calculated according to EN 12354-2, $L_{\text{Fb,e}}$ should be given by the equipment producer and $L_{\text{Fb,tap}}$ is usually estimated from literature [6].

Note that this approach requires a measurement method for impact sound of wall, which does not exist yet. Nevertheless, the existing data base for impact sound of heavy floors could also be used for heavy walls.

## 2.3. General case

### 2.3.1. General

The general case corresponds to any mobility conditions between source and receiver and any type of receiving building elements (heavy or lightweight). The key input parameter for the transmission through the building structure is then a quantity called unit power equipment sound level (symbol $L_{\text{ne},0,i}$), which represents the normalized sound pressure level in the receiving room produced by a structure-borne sound source injecting a unit power (1Watt) at different position on the element *i* considered in the source room. This quantity can include all the paths from the element to the receiving room ($L_{\text{ne},0,\text{all},i}$), or can be reduced to a particular (isolated) flanking path *ij* ($L_{\text{ne},0,\text{f},ij}$) or direct path *ii* ($L_{\text{ne},0,ii}$). The use of $L_{\text{ne},0}$ in predicting sound levels generated on site by equipment depends on the building type and can lead to four different methods, which are detailed in the following sub-sections 2.3.2. to 2.3.5.

### 2.3.2. All transmission paths considered globally

According to EN ISO 10848-1, all transmission paths can be globally characterized by a quantity called normalized spatial average transmission function (symbol $D_{\text{TF,av,n},i}$) between normalized average sound pressure level in the receiving room and a known (measured) installed power, averaged over several excitation positions on the building element *i* considered. The unit power equipment sound level $L_{\text{ne,0,all}}$ including all the paths can then easily be deduced from $D_{\text{TF,av,n}}$:

$$L_{\text{ne},0,\text{all},i} = D_{\text{TF,av,n},i} + L_{\text{W0}} \qquad (2)$$

where $L_{\text{W0}}$ is the power level in dB ref. $10^{-12}$ Watt of a unit power source ($L_{\text{W0}}$=120 dB).

The noise level generated by an equipment mounted on element *i* in the source room is then straightforward:

$$L_{\text{n,s},i} = L_{\text{ne},0,\text{all},i} + L_{\text{Winst},i} - L_{\text{W0}} \qquad (3)$$

where $L_{\text{Winst},i}$ is the installed power of the equipment calculated according to EN 15657 from the source characteristics given by the producer and the building element mobility usually estimated from literature.

This method can be applied to any type of receiving building elements, heavy or lightweight (Type A or Type B respectively). A data base of $L_{\text{ne,0,all}}$ values for different building configurations can be created and equation (3) used as a rough simplified prediction tool.

### 2.3.3. Each transmission path *ij* considered globally

Each transmission path *ij* considered globally is characterized by the normalized flanking equipment sound pressure level $L_{\text{ne},0,\text{f},ij}$, which is defined and its measurement procedure described in EN ISO 10848-1.

The noise level generated by an equipment mounted on element *i* in the source room and transmitted through path *ij* is again straightforward:

$$L_{\text{n,s},ij} = L_{\text{ne},0,\text{f},ij} + L_{\text{Winst},i} - L_{\text{W0}} \qquad (4)$$

This method is usually applied to Type B elements, but could also be applied to Type A elements. Its use requires creating a data base of $L_{\text{ne},0,\text{f},ij}$ values for different building junctions.

### 2.3.4. Each transmission path *ij* deduced from the performance of the elements

In EN 12354-2, the impact sound level transmitted through path *ij* can be estimated from the performance of the elements. The method can be applied to both Type A and type B elements; however, the formulae are different. For the equipment sound level, the same formulae can be used.

In the case of Type A elements, the formula is the following (assuming no additional layer on the elements for clarity):

$$L_{\mathrm{n,s},ij} = L_{\mathrm{ne},i} + (R_i - R_j)/2 - \overline{D_{\mathrm{v},ij}} - 10\lg(\sqrt{(S_j/S_i)}) \quad (5)$$

where $L_{\mathrm{ne},i}$ is the normalized (direct) equipment sound level of element *i*, $R_i$ and $R_j$ the sound reduction indices of elements *i* and *j*, $\overline{D_{\mathrm{v},ij}}$, the junction direction-averaged vibration level difference, $S_i$ and $S_j$ the surface area of elements *i* and *j*.

$L_{\mathrm{ne},i}$ can be calculated using formula (4) applied to the direct path *ii*:

$$L_{\mathrm{ne},i} = L_{\mathrm{ne,0},ii} + L_{\mathrm{Winst},i} - L_{\mathrm{W0}} \quad (6)$$

where $L_{\mathrm{ne,0},ii}$ is the unit power direct equipment sound level of element *i* measured according to EN 10848-1.

In the case of Type B elements, a different formula is used (assuming no additional layer on the elements for clarity):

$$L_{\mathrm{n,s},ij} = L_{\mathrm{ne},i} + (R_i - R_j)/2 - \overline{D_{\mathrm{v},ij,\mathrm{n}}} - 10\lg(S_i/(l_0 l_i)) \quad (7)$$

where $\overline{D_{\mathrm{v},ij,\mathrm{n}}}$ is the junction normalized direction-averaged vibration level difference, and $l_i$ the junction length ($l_0$=1m). $R_i$ and $R_j$ relate to resonant transmission only.
The method can be summarized as follows: (i) calculate $L_{\mathrm{n,e},i}$ using formula (6) and (ii) use it as input data in EN 12354-2 to estimate the equipment noise level in situ.

#### 2.3.5. Each transmission path *ij* characterized by the flanking sound reduction index

According to EN 12354-5:2009, the normalized sound pressure level $L_{\mathrm{n,s},ij}$ in the receiving room for each transmission path *ij* can be estimated as:

$$L_{\mathrm{n,s},ij} = L_{\mathrm{Winst},i} - D_{\mathrm{sa},i} - R_{ij,\mathrm{ref}} - 10\lg(S_i/S_{\mathrm{ref}}) - 10\lg(A_{\mathrm{ref}}/4) \quad (8)$$

where $D_{\mathrm{sa},i}$ is an adjustment term, which transfers the injected structure-borne sound power to the incident air-borne sound power that excites the same energy level in the supporting building element *i*, considering only free vibrations. The knowledge of this “equivalent” incident airborne power allows the use of EN 12354-1 (airborne sound insulation) for predicting equipment noise. $R_{ij,\mathrm{ref}}$ is the flanking sound reduction index in decibels, calculated in EN 12354-1 with reference to the area $S_{\mathrm{ref}}$ = 10m$^2$. And $A_{\mathrm{ref}}$ = 10m$^2$.

This method is, like EN 12354-1, valid for any type of elements (Type A or type B).

Moreover, applying Formula (8) to direct path *ii* and injecting a unit power leads to:

$$D_{\mathrm{sa},i} = L_{\mathrm{W0}} - L_{\mathrm{ne,0},ii} - R_i - 10\lg(S_i/S_{\mathrm{ref}}) - 10\lg(A_{\mathrm{ref}}/4) \quad (9)$$

which allows an estimate of $D_{\mathrm{sa},i}$ from the element sound reduction index $R_i$ and the element unit power direct equipment sound pressure level $L_{\mathrm{ne,0},ii}$ measured according to EN 10848-1. In the case of type B elements, $R_i$ relates to resonant transmission only.
The method can be summarized as follows: use EN 12354-5:2009 which requires (i) calculating $L_{\mathrm{Winst},i}$ according to EN 15657 from the source characteristics given by the producer and the building element mobility usually estimated from literature, (ii) calculating $D_{\mathrm{sa},i}$ using formula (9) and (iii) using EN 12354-1 to determine $R_{ij,\mathrm{ref}}$.

## 3. Brief discussion

Measuring the unit power equipment sound level $L_{\mathrm{ne,0}}$ of an element requires a known structural source strong enough to generate measurable sound levels in the receiving room; an instrumented hammer with moderate shocks for the sake of linearity can be used as known source, which is simple and practical [8]. Sources such as waste water pipes, which generate low structure-borne sound levels barely measurable (using EN 14366, [9]) could then be characterized by purely vibrational measurements (using EN 15657), less sensitive to background noise because of the use of a known more powerful source, and their structure-borne sound levels calculated using equation (6). A detailed study of this case is presented in [10].

EN 15657 allows characterizing sources installed on non -isolated reception plate, which leads to the possibility of in situ characterization of spatially extended sources such as lifts. Usually installed on heavy building structures, lifts could then be predicted using the method described in section 2.2, their blocked force levels being measured on site at the fixation points to the building structure.

## 4. Conclusion

This paper has been focused on structure-borne sound sources and has shown that:

- in the case of heavy constructions, where the receiver mobility is likely to be much lower than the equipment mobility, in-situ equipment noise can be simply predicted from the in-situ impact noise of the element, obtained using EN 12354-2 and corrected for the difference in blocked force level between equipment and tapping machine.
- in the general case, which includes lightweight constructions, the prediction can be made using only two key quantities: the equipment installed power $L_{\mathrm{Winst},i}$ injected to the receiving element $i$ and determined according to EN 15657, and the element unit power equipment sound level $L_{\mathrm{ne},0,i}$ , which can include all the paths from the element $i$ to the receiving room ($L_{\mathrm{ne},0,\mathrm{all},i}$), thus leading to a rough and simple prediction method, or can be reduced to a particular (isolated) flanking path $ij$ ($L_{\mathrm{ne},0,\mathrm{f},ij}$) or direct path $ii$ ($L_{\mathrm{ne},0,ii}$). These expressions of unit power equipment sound level are all determined according to EN ISO 10848-1. $L_{ne,0,f,ij}$ is usually used for lightweight elements as $L_{ne,0,ii}$ can be used for any building element, leading to two prediction approaches, linked to either impact noise prediction (EN 12354-2) or airborne noise prediction (EN 12354-1).

More experimental work on specific sources is now required to validate these prediction approaches and give practical information on the characterization of these sources and the uncertainties related to both their characterization and the prediction method itself.

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