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ON THE ROOM CORRECTION OF TRANSIENT SOUND PRESSURE LEVELS GENERATED BY BUILDING SERVICES

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Abstract

Noise from building service equipment is often neither ideally stationary nor ideally impulsive, but exhibits a complex temporal structure. Requirements for sound insulation against noise from building service equipment in Germany are given in terms of $L_{\mathrm{AF,max,n}}$. This raises the question of how such noise should be treated in the prediction method according to EN 12354-5 and EN 15657, which is presently formulated for stationary excitation. While levels of stationary sounds are commonly normalized using the equivalent absorption area of the receiving room, EN ISO 10140-3 provides an alternative correction for ideal impulsive excitation based on receiving room volume and reverberation time. Building on previous work, this paper investigates how EN 12354-5 and EN 15657 can be extended towards transient excitation. A universal room-correction method is proposed that accounts for both room properties and signal transience. Validation measurements in a building-like test stand and in a reverberation chamber with varied reverberation times show that the proposed universal (transience-adaptive) correction reduces the influence of the room condition and improves the agreement between measured and predicted maximum sound pressure levels for transient signals.

Keywords: *building service equipment, transient signals, room correction, EN 12354-5, EN 15657*

1. Introduction

Building service equipment can be a relevant contributor to noise in buildings. EN 12354-5:2023 [1] specifies a calculation procedure to predict sound pressure levels from building service equipment, while EN 15657:2017 [2] defines measurement methods to determine key source quantities for this method, most notably the blocked force for structure-borne excitation. Both standards have been developed and validated primarily for stationary operating conditions and therefore employ energy-equivalent quantities (e.g. L_{eq}).

In practice, many sources exhibit pronounced temporal variability (start/stop events, switching, valve operations, impacts), i.e. signals with significant *transience*. In Germany, compliance assessment for noise from building services is therefore based on maximum A-weighted, fast time-weighted and room-normalized sound pressure levels $L_{\mathrm{AF,max,n}}$ according to DIN 4109-1 [3]. This conceptually differs from an L_{eq}-based approach.

Previous work by the authors has shown that the measurement method to determine the blocked force according to EN 15657 can be adapted for transient excitation in a straightforward manner [4]. The core idea is to determine, on the reception plate, a fast time-weighted maximum velocity level $L_{v,\mathrm{F,max}}$ instead of the energy-equivalent velocity level $L_{v,\mathrm{eq}}$ and to insert $L_{v,\mathrm{F,max}}$ into the existing EN 15657 relations. This yields a method for determining the installed structure-borne sound power and blocked force levels under transient excitation, without changing the underlying measurement setup or the basic formulation of the standard.

Building on this finding, this paper assesses the applicability of EN 12354-5 to non-stationary excitation using transient-adapted source quantities derived from EN 15657. The EN 12354-5 prediction method [1] combines measured source quantities with structural and airborne sound transmission properties of the building, which may be obtained from calculations or measurements. For structure-borne sound sources, the normalized equivalent sound pressure level $L'_{\mathrm{ne,s}}$ can be written as

$$L'_{\mathrm{ne,s}} = L'_{\mathrm{n}} + L_{F\mathrm{b,eq}} - L_{F\mathrm{b,eq,stm}} \tag{1}$$

The expression applies when the mobility of the source is much greater than the mobility of the receiving

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structure, which is typically the case in heavyweight buildings. Here, L'_{n} denotes the normalized impact sound pressure level in an adjacent room caused by the standard tapping machine, $L_{F\mathrm{b,eq}}$ is the equivalent[1] blocked force level of the source, and $L_{F\mathrm{b,eq,stm}}$ is the blocked force level of the standard tapping machine. Reference values for $L_{F\mathrm{b,eq,stm}}$ are given in EN 12354-5 [1], while the calculation procedure for L'_{n} is specified in EN ISO 12354-2 [5].

A critical issue is the room normalization implicit in the parameter L'_{n} in Equation (1). The prediction is referenced to an absorption-area based correction that is appropriate for (quasi-)stationary signals, but becomes questionable for transient signals. For impulsive excitation, provided by the standard rubber ball, EN ISO 10140-3 [6] specifies an alternative normalization based on room volume and reverberation time. This normalization explicitly accounts for the time constant necessary to build the fast-weighted level ($\tau_{\mathrm{F}} = 0.125\,\mathrm{s}$). Real building-service noise lies between these limiting cases. Hence, predicting maximum levels requires a reverberation time correction that transitions between the stationary and impulsive references. The objective of this work is therefore to derive a universal room-correction approach for transient building-service noise based on an estimate of signal transience.

1.1. Room Correction Methods

For comparability between different receiving rooms, measured or predicted sound pressure levels are typically normalized by a room correction. For stationary excitation, a common approach is normalization by the equivalent absorption area. Using the measured maximum fast time-weighted levels $L_{\mathrm{F,max}}$, this yields

$$L_{\mathrm{F,max,n}} = L_{\mathrm{F,max}} + 10\lg\left(\frac{A_1}{A_0}\right) \tag{2}$$

where A_1 is the equivalent absorption area of the receiving room and $A_0 = 10\,\mathrm{m}^2$ is the reference absorption area. Assuming a diffuse sound field,

$$A_1 = 0.16 \cdot \frac{V_1}{T_1} \tag{3}$$

with room volume V_1 and reverberation time T_1. Inserting Equation (3) into Equation (2) leads to the equivalent formulation

$$L_{\mathrm{F,max,n}} = L_{\mathrm{F,max}} + 10\lg\left(\frac{V_1}{V_0}\right) - 10\lg\left(\frac{T_1}{T_0}\right) \tag{4}$$

where V_0 and T_0 denote the reference room volume and reference reverberation time corresponding to A_0. High reverberation times particularly affect transient sounds. A short energy injection is temporally smeared by multiple reflections, such that time-weighted maxima increasingly depend on the reverberant decay rather than on the direct contribution only. For impulsive excitation, provided by the standard rubber ball, EN ISO 10140-3 [6] specifies an alternative room correction that uses the room volume and reverberation time together with the time constant $\tau_{\mathrm{F}} = 0.125\,\mathrm{s}$ necessary to build the maximum fast-weighted levels. The corresponding corrected maximum level can be written as

$$L_{\mathrm{F,max},V,T} = L_{\mathrm{F,max}} + 10\lg\left(\frac{V_1}{V_0}\right) - 10\lg(\mathrm{Corr_T}) \tag{5}$$

with

$$\mathrm{Corr_T} = \frac{1 - C_0^{-1}}{1 - C_1^{-1}} \cdot \left(\frac{C_1^{(1-C_1)^{-1}} - C_1^{-(1-C_1^{-1})^{-1}}}{C_0^{(1-C_0)^{-1}} - C_0^{-(1-C_0^{-1})^{-1}}}\right), \quad \text{where} \quad C_j = \frac{T_j}{13.82 \cdot \tau_{\mathrm{F}}} \tag{6}$$

EN ISO 10140 uses a reference volume of $V_0 = 50\,\mathrm{m}^3$ for this impulse-based correction. To ensure consistent reference conditions when comparing different correction schemes, it is convenient to align the reference volume with the absorption-area reference used in Equation (2). Using $A_0 = 10\,\mathrm{m}^2$ and $T_0 = 0.5\,\mathrm{s}$ gives

$$V_0 = \frac{A_0\,T_0}{0.16} = 31.25\,\mathrm{m}^3 \tag{7}$$

In summary, two well-established correction procedures exist: one suited to ideally stationary excitation (Equation (4)) and one suited to ideally impulsive excitation (Equation (5)). The only difference between the two lies in the reverberation-time-dependent term, i.e. $10\lg(T_1/T_0)$ versus $10\lg(\mathrm{Corr_T})$. Figure 1 shows the difference between these terms.

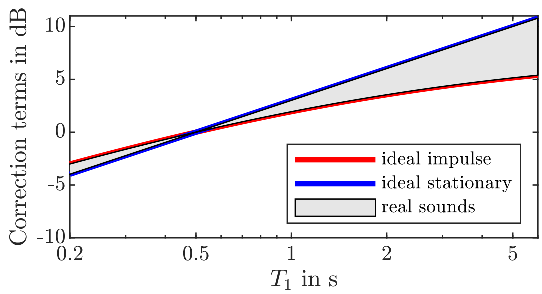

Figure 1: Reverberation-time-dependent correction terms for ideally stationary (blue) and ideally impulsive (red) sounds. Real sounds lie within the grey-shaded region. (Real rooms rarely exhibit reverberation times $< 0.5\,\mathrm{s}$.)

Real-world signals typically fall between these two extremes. A universal room correction therefore requires information about the *transience* of the excitation signal in order to select an appropriate interpolation between both cases.

[1] In EN 15657, the index "eq" for blocked force levels refers to *spatial averaging* over the contact points of the source.

2. Universal Room Correction

2.1. Estimation of Transience

In this study, the estimation of signal transience is integrated into the source characterization performed on the reception plate. Using the accelerometers required to determine the spatially averaged plate velocity in the reception plate method (EN 15657), the difference between the fast time-weighted maximum velocity level and the slow time-weighted maximum velocity level is evaluated:

$$\Theta_{\mathrm{Tr}} = L_{v,\mathrm{F,max}} - L_{v,\mathrm{S,max}} \tag{8}$$

The level difference Θ_{Tr} serves as an operational measure of the transience of the excitation signal and forms the basis for the subsequent room correction.

Microphone-based estimates in receiving rooms are not suitable for this purpose, because reverberation and reflections affect transient sounds. Short events are temporally smeared and thus appear less transient. In contrast, the reception plate exhibits very short structural decay times, so that a noticeable temporal broadening of transient excitation does not occur and the determination of maximum levels is only marginally affected. For an ideally stationary excitation, $\Theta_{\mathrm{Tr}} = 0\,\mathrm{dB}$. For an ideal impulsive excitation, $\Theta_{\mathrm{Tr}} \approx 9\,\mathrm{dB}$, corresponding to $10\lg(\tau_\mathrm{S}/\tau_\mathrm{F})$ with $\tau_\mathrm{F} = 0.125\,\mathrm{s}$ and $\tau_\mathrm{S} = 1\,\mathrm{s}$. Real-world signals yield Θ_{Tr} values between these limits, where larger values indicate a more pronounced transience.

2.2. Universal Room Correction

Based on the estimated transience, a universal room correction is defined that is applicable to signals of arbitrary transience. The method uses the absorption-area-based normalization for stationary signals (Equation (4)) as a baseline and introduces an additional, transience-dependent correction term $\Delta L_{\mathrm{Trans}}$:

$$\Delta L_{\mathrm{Trans}} = \left(10\lg\left(\frac{T_1}{T_0}\right) - 10\lg(\mathrm{Corr_T})\right)\cdot\frac{\Theta_{\mathrm{Tr}}}{9} \tag{9}$$

Here, the first bracketed expression represents the difference between the reverberation-time-dependent correction terms associated with the stationary and the impulsive room correction method (Equations (4) and (5)). The factor $\Theta_{\mathrm{Tr}}/9$ provides a linear interpolation between both limiting cases, see also Figure 2. The resulting universally corrected fast maximum level is then obtained as

$$L_{\mathrm{F,max,Trans}} = L_{\mathrm{F,max,n}} + \Delta L_{\mathrm{Trans}} \tag{10}$$

With this formulation, $\Delta L_{\mathrm{Trans}} \to 0$ for ideally stationary excitation ($\Theta_{\mathrm{Tr}} = 0\,\mathrm{dB}$), so that the method reduces to the conventional absorption-area normalization (blue curve). For ideally impulsive excitation ($\Theta_{\mathrm{Tr}} \approx 9\,\mathrm{dB}$), the correction reaches its maximum and shifts the room normalization towards the impulse-based reference condition governed by $\mathrm{Corr_T}$ (red curve).

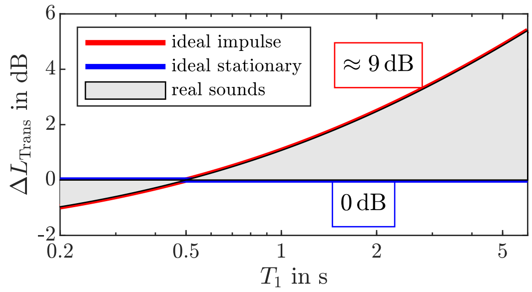

Figure 2: Correction term $\Delta L_{\mathrm{Trans}}$ as the difference between the two reverberation-time-dependent correction terms (see Figure 1). The correction for real sounds lies within the grey-shaded region, between the correction for ideally stationary (blue) and ideally impulsive (red) sounds.

3. Measurements and Validation

To study signals with different transience, stationary white noise and time-varying (ramped) noise signals were employed in two measurement series. All excitation signals had a duration of 13 s. An overview of the ramped noise signals is shown in Figure 3. For these ramped signals, both rise time and ramp height were varied. Rise times of 0.125 s, 0.5 s, 1 s, 2 s and 5 s were combined with ramp heights of 10 dB, 20 dB, 30 dB and 40 dB.

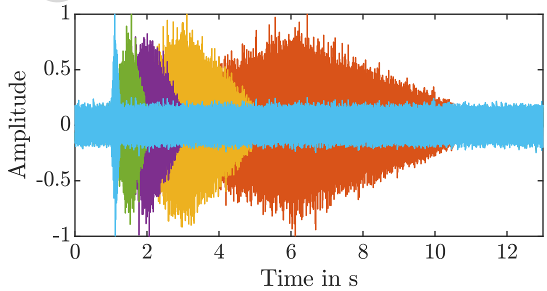

Figure 3: Ramped noise signals with different ramp durations (rise times) and a ramp height of 10 dB. Shown are rise times of 0.125 s (blue), 0.5 s (green), 1 s (violet), 2 s (yellow), and 5 s (orange).

3.1. Building-like Test Stand

The signals with different transience were first characterized using shaker excitation on a reception plate according to EN 15657. These source characterization data were used to calculate predicted normalized maximum sound pressure levels in a receiving room according to EN 12354-5. In a second step, the same signals were measured in a building-like test stand with a shaker mounted on the separating installation wall between a source room and an adjacent receiving room. In the receiving room, $L_{\mathrm{F,max}}$ was determined from six spatially distributed microphones. Details on the experimental setup and the test environments are provided in [4], [7].

To assess the influence of the room on transient excitation, the reverberation time of the receiving room was varied between two conditions. These two room conditions, shown in Figure 4, represent a shorter reverberation time typical of a furnished living space and a longer reverberation time corresponding to a more reverberant room. This variation was introduced deliberately, as transient signals are expected to be particularly sensitive to reverberation effects.

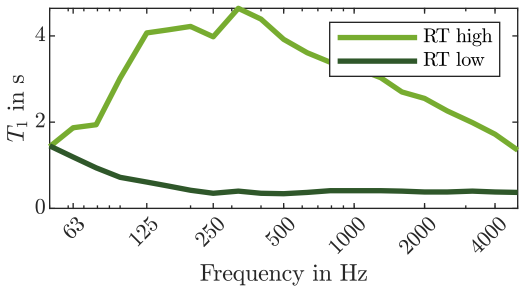

Figure 4: Reverberation times in the receiving room of the building-like test stand.

The measured sound pressure levels in the receiving room were normalized using different room-correction approaches, namely the absorption-area-based correction (Equation (4)), the impulse-based correction (Equation (5)), and the proposed universal (transience-adaptive) correction (Equation (10)). The normalized measured levels were compared with the predicted levels using Equation (1). In this study, the normalized impact sound pressure level L'_n was determined by measurement instead of calculation according to EN ISO 12354-2. This comparison serves two purposes: First, to evaluate whether the prediction according to EN 12354-5 is consistent with the measurement result, i.e. whether the difference between measured and predicted values is close to zero. And second, to assess whether the room-correction method is able to minimize the influence of the receiving room reverberation time, i.e. whether similar results are obtained for both the short and the long reverberation time condition.
Figure 5 illustrates this comparison for selected excitation signals: A stationary noise signal, the ramped noise signal 2 s/40 dB, and the ramped noise signal 0.125 s/40 dB. Based on the reception plate measurements, the transience Θ_{Tr} defined in Equation (8) was calculated to 1 dB, 2 dB, and 7 dB (rounded to integers) for the selected signals.
While good agreement between measured and predicted values can be achieved (0 dB equals no difference between measurement and prediction), the results also show that the sensitivity to room condition (difference of light and dark green data points) depends strongly on the transience of the excitation and on the applied room-correction method (Equations (4) and (5)). In particular, the universal (transience-adaptive) correction (Equation (10)) leads to the most consistent results across both reverberation time conditions.

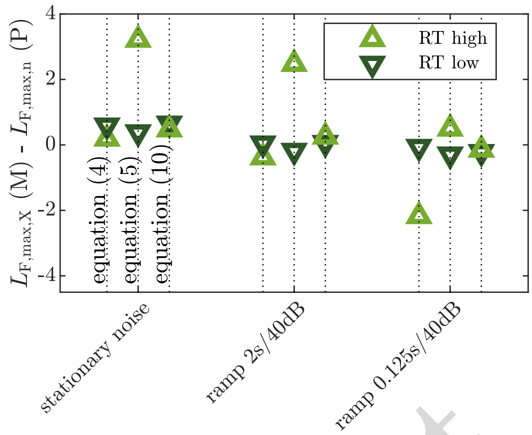

Figure 5: Difference between measured (M) and predicted (P) sound pressure levels. The index X denotes the room-correction method applied, Equations (4), (5), and (10).

However, this comparison of single number quantities does not fully reveal the underlying mechanisms, since both the prediction method and the room correction are performed on a frequency-band basis. Figure 6 shows the frequency-dependent difference between measurement and prediction for one representative transient excitation signal, the ramped noise signal 0.125 s/40 dB.

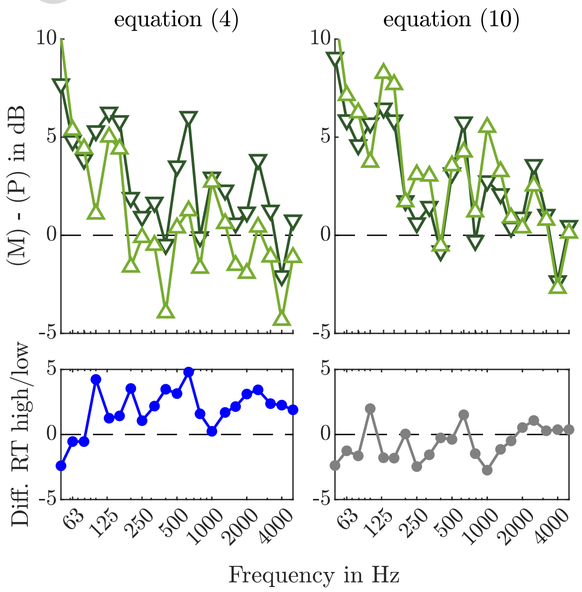

Figure 6: Upper part: Difference between measured (M) and predicted (P) sound pressure levels over frequency, using different room correction methods on a ramp signal corresponding to 0.125 s/40 dB for different reverberation time conditions. Lower part: Difference between these reverberation time conditions over frequency.

In the upper part of Figure 6, frequency-dependent deviations remain visible. These deviations between measured and predicted values persist due to uncertainties

in the prediction method according to EN 12354-5. In the lower part of Figure 6, it can be observed that the universal room correction reduces the differences between the two reverberation time conditions (right side of Figure 6).
The comparison between measured and predicted values to evaluate the suitability of the room correction method in Figure 5 can therefore be misleading, as the predicted values also contain the uncertainties associated with the calculations according to EN 12354-5. To investigate the influence of the room condition and the room correction independently from the prediction method, a second study was conducted.

3.2. Reverberation Chamber

In a subsequent measurement series, the previously shown signals with different transience were investigated in a reverberation chamber with a volume of $V = 59\,\mathrm{m}^3$ using loudspeaker excitation. This provides the advantage that room-correction methods can be evaluated directly from measurements, i.e. without the additional uncertainty introduced by a prediction model. The reverberation time of the chamber was adjusted to three distinct conditions (see Figure 7).

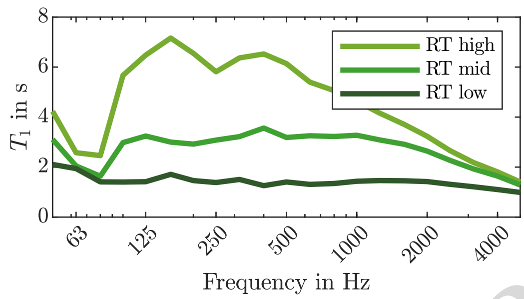

Figure 7: Reverberation times in the chamber.

Excitation signals with variable transience including selected ramped-noise signals from Figure 3 were reproduced via a loudspeaker and recorded using eight microphones distributed within the chamber. The analysis was carried out on frequency-dependent sound pressure levels. The corresponding frequency-dependent room-correction methods were applied band-wise. Analogous to the building-like test-stand evaluation, the room-corrected levels were subsequently condensed into single-number values of normalized maximum levels.
Figure 8 presents the results of the reverberation chamber measurements. For each representative signal (stationary noise, a 2 s/40 dB ramp, a 0.5 s/40 dB ramp, and a 0.125 s/40 dB ramp), the Figure 7 shows the difference between the measured, room-corrected levels obtained for the two most extreme reverberation time conditions, i.e. $\Delta L_{p,\mathrm{F,max,X}} = L_{p,\mathrm{F,max,X}}(\mathrm{RT_{high}}) - L_{p,\mathrm{F,max,X}}(\mathrm{RT_{low}})$. Thus, the plotted values represent the difference between the measurements corresponding to the light green curve (highest reverberation time) and the dark green curve (lowest reverberation time) shown in Figure 7. For the signals shown, the transience determined by means of Θ_{Tr} is 1 dB, 2 dB, 4 dB, and 7 dB (rounded to integers). For this part of the analysis, the difference $L_{\mathrm{F,max}} - L_{\mathrm{S,max}}$ was calculated directly from the audio file. Compared with values derived from reception plate measurements, no significant difference was observed beyond the inherent measurement uncertainty.

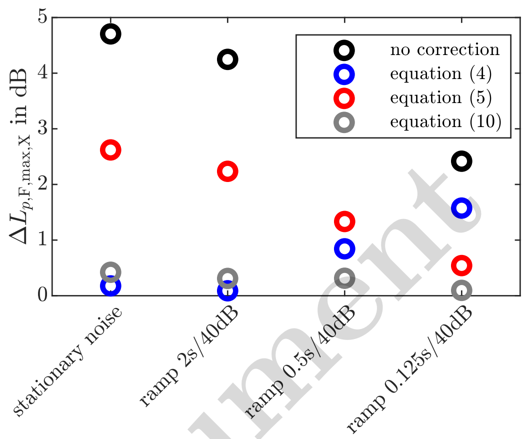

Figure 8: Difference of measured and room corrected sound pressure levels in the reverberation chamber $\Delta L_{p,\mathrm{F,max,X}}$ (RT high - RT low in Figure 7) using different room correction methods on signals with varying transience. The index X denotes the room-correction method applied, Equations (4), (5), and (10).

The results are shown for when the levels are not room corrected (black), the absorption-area based correction (Equation (4), blue), the impulse-based correction (Equation (5), red), and the proposed universal (transience-adaptive) correction (Equation (10), grey). The trends are consistent with the findings from the building-like test stand: The absorption-area approach (Equation (4)) yields good agreement for stationary excitation (e.g. stationary noise) but there are increasing deviations for measured levels in different reverberation time conditions as transience increases (e.g. ramp 0.125 s/40 dB). The impulse-based correction (Equation (5)) performs best for strongly transient signals and is less suitable for stationary noise. The universal (transience-adaptive) correction (Equation (10)) provides the most uniform agreement across all excitation conditions and across the reverberation time settings. At the same time, it is worth noting that the conventional absorption-area normalization does not produce unreasonable results in general. Rather, its limitations become most apparent for highly transient excitation and elevated reverberation times, where a transience-dependent correction is beneficial.
As for the building-like test stand, a frequency-dependent evaluation was carried out for the reverberation-chamber measurements in order to assess how the different room-correction methods perform over frequency. For this purpose, the most transient excitation investigated, i.e. the 0.125 s/40 dB ramp signal, was selected as a representative example.

The results are shown in Figure 9 as the frequency-dependent difference between the levels obtained in the highest and lowest reverberation time conditions, corresponding to the light and dark green curves in Figure 7, respectively. In this representation, small values indicate that the respective room-correction method largely removes the influence of the reverberation time.

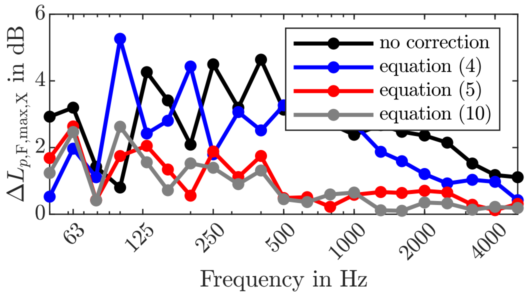

Figure 9: Frequency-dependent difference of measured and room corrected sound pressure levels in the reverberation chamber $\Delta L_{p,\mathrm{F,max,X}}$ (RT high - RT low in Figure 7) using different room correction methods on the transient ramped noise signal 0.125 s/40 dB. The index X denotes the room-correction method applied, Equations (4), (5), and (10).

Figure 9 shows that the uncorrected results exhibit a clear dependence on the reverberation time condition. Applying the correction derived for stationary excitation according to Equation (4) does not remove this effect for the highly transient signal considered here; substantial frequency-dependent deviations remain. The impulse-based correction according to Equation (5) reduces these differences, as expected for a signal with higher transience. The smallest deviations across the investigated frequency range are obtained with the proposed universal (transience-adaptive) correction according to Equation (10).
Overall, the results indicate that the universal correction is effective regardless of signal transience and reverberation time.

4. Summary

This paper addresses the limitations of existing prediction procedures for building-service noise when the excitation is non-stationary. While EN 12354-5 and EN 15657 are fundamentally formulated for stationary conditions using energy-equivalent levels, practical sources often exhibit transient behavior and are assessed in Germany using maximum, time-weighted levels.
A central contribution of this work is a universal reverberation time correction that bridges the two limiting room-normalization concepts: The absorption-area based correction suitable for (quasi-)stationary signals and the impulse-based correction suitable for impulsive excitation. The required transience is estimated from accelerometer measurements on the reception plate to calculate the level difference $L_{v,\mathrm{F,max}} - L_{v,\mathrm{S,max}}$, and is used to derive the transience-dependent correction term $\Delta L_{\mathrm{Trans}}$. Measurements in a building-like test stand demonstrate that the proposed approach yields consistently small deviations between EN 12354-5-based predictions and room-corrected receiving room measurements, while substantially reducing the sensitivity to the receiving room reverberation time. Complementary measurements in a reverberation chamber confirm the same trends without the additional uncertainty of the prediction method, supporting the conclusion that the proposed universal correction provides a robust transition between stationary and impulsive reference conditions.

5. Acknowledgments

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