

NRC Publications Archive Archives des publications du CNRC

Influence of receive room properties on impact sound pressure level measured with heavy impact sources

Schoenwald, S.; Zeitler, B.; Nightingale, T. R. T.

This publication could be one of several versions: author's original, accepted manuscript or the publisher's version. /
La version de cette publication peut être l'une des suivantes : la version prépublication de l'auteur, la version acceptée du manuscrit ou la version de l'éditeur.

Publisher's version / Version de l'éditeur:

1st EAA: EUROREGIO 2010 Congress on Sound and Vibration: [Proceedings], pp. 1-8, 2010-09-15

NRC Publications Archive Record / Notice des Archives des publications du CNRC :

<https://nrc-publications.canada.ca/eng/view/object/?id=3bd2631d-f694-4296-9a5d-ce2ecc3746fa>

<https://publications-cnrc.canada.ca/fra/voir/objet/?id=3bd2631d-f694-4296-9a5d-ce2ecc3746fa>

Access and use of this website and the material on it are subject to the Terms and Conditions set forth at

<https://nrc-publications.canada.ca/eng/copyright>

READ THESE TERMS AND CONDITIONS CAREFULLY BEFORE USING THIS WEBSITE.

L'accès à ce site Web et l'utilisation de son contenu sont assujettis aux conditions présentées dans le site

<https://publications-cnrc.canada.ca/fra/droits>

LISEZ CES CONDITIONS ATTENTIVEMENT AVANT D'UTILISER CE SITE WEB.

Questions? Contact the NRC Publications Archive team at

PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca. If you wish to email the authors directly, please see the first page of the publication for their contact information.

Vous avez des questions? Nous pouvons vous aider. Pour communiquer directement avec un auteur, consultez la première page de la revue dans laquelle son article a été publié afin de trouver ses coordonnées. Si vous n'arrivez pas à les repérer, communiquez avec nous à PublicationsArchive-ArchivesPublications@nrc-cnrc.gc.ca.



Influence of receive room properties on impact sound pressure level measured with heavy impact sources

NRCC-53550

Schoenwald, S.; Zeitler, B.; Nightingale,
T.R.T.

September 2010

A version of this document is published in / Une version de ce document se trouve dans:
1st EAA - EUROREGIO 2010 Congress on Sound and Vibration, Ljubljana,
Slovenia, September-15-18, 2010, pp. 1-8

The material in this document is covered by the provisions of the Copyright Act, by Canadian laws, policies, regulations and international agreements. Such provisions serve to identify the information source and, in specific instances, to prohibit reproduction of materials without written permission. For more information visit <http://laws.justice.gc.ca/en/showtdm/cs/C-42>

Les renseignements dans ce document sont protégés par la Loi sur le droit d'auteur, par les lois, les politiques et les règlements du Canada et des accords internationaux. Ces dispositions permettent d'identifier la source de l'information et, dans certains cas, d'interdire la copie de documents sans permission écrite. Pour obtenir de plus amples renseignements : <http://lois.justice.gc.ca/fr/showtdm/cs/C-42>



National Research
Council Canada

Conseil national
de recherches Canada

Canada

Influence of receive room properties on impact sound pressure level measured with heavy impact sources

Stefan SCHOENWALD^a, Berndt ZEITLER^a and Trevor R.T. NIGHTINGALE^a

^a National Research Council Canada, Institute of Research in Construction
1200 Montreal Rd, Ottawa K1A 0R6, CANADA, e-mail: stefan.schoenwald@nrc-cnrc.gc.ca

ABSTRACT

One important issue in building acoustics is the testing and rating of the impact sound isolation of floor assemblies. Although the basic principal of impact testing is equal in all standardized test procedures – i.e. the test specimen is excited with a structural source and the resulting sound pressure level is measured in the receive room – there are also major differences. According to ISO 140 the well known tapping machine excites the test specimen with its five dropping steel hammers that produce a steady-state excitation signal. In the receive room the equivalent sound pressure level is averaged over time and space. Normalization of the impact sound pressure level to room volume and to reverberation time allows comparison of measurement results that are measured in different facilities or in-situ. On the other hand, according to JIS 1418 a well-defined small car tire or a rubber ball is dropped from a particular height on the floor assembly. In the receive room the fast-weighted maximum sound pressure level of the sound impulse due to the impact is averaged over several drop and receiver positions. However, in the post processing of the data the properties of the receive room are not taken into account. In a recent study heavy impact tests were done in a test facility that is significantly bigger and has also a much longer reverberation time than rooms in common dwellings. To enable a comparison and transfer of the test results to the impact sound isolation that would be measured in real buildings, the effect of room volume and of reverberation time on the sound pressure level of the impulses is assessed in this paper.

1. INTRODUCTION

Currently different standardized methods exist to test and rate the impact sound isolation of floor assemblies. The same basic test procedure is used both in the laboratory and in the field. The floor assembly under test is excited structurally by an impact source and the resulting sound pressure level is measured in a receive room.

ISO 140 is most common method for laboratory and field measurements. The floor is excited with the tapping machine that produces a steady state impact noise in the receive room where the time and space average sound pressure level is measured. The measured sound levels can be normalized by the reverberation time and room volume to obtain values that are situation independent and enable comparison with assemblies measured elsewhere. The tapping machine most effectively excites floors with hard surfaces in the mid and high frequency range similar to walkers with hard heeled shoes.

In the Japanese JIS 1418-2 a different approach is used. The floor is excited in the low frequency range by an impact of a heavy soft source that is intended to simulate people walking barefoot or children jumping. In addition to the impact source and the frequency range being different from ISO 140, so too is the measurement procedure which will be reviewed in the following section before presenting results to show the influence of the receive room properties, i.e. room volume and absorption, on the measured heavy impact sound pressure level.

2. IMPACT SOUND MEASUREMENT ACCORDING TO JIS 1418

Two impact sources are defined in the field measurement method according to JIS 1418-2. The first is a small car tire that is dropped from 85 cm height– the so-called “bang machine”. The second is a rubber ball that is dropped from 1 m height on the test floor – the “ball”. The impact of both sources excites floors very effectively in the low frequency range 32 – 125 Hz and produces an impulse in the receive room. Since the time averaged sound pressure level is not suitable to describe the sound power in the room due to a transient event – it depends also on the chosen averaging time – the maximum fast-weighted level $L_{F,max}$ of the impact is measured in octave bands from 63 Hz to 500 Hz.

Octave band filtering is used since it affects signals less than third-octave band filtering which distorts signals significantly in the low frequency range because of the small bandwidth and the resulting ringing of the filters. Even though recent research reports suggest differently [1], [2], it is also assumed that the maximum Fast (F)-weighted level $L_{F,max}$ is a measure of the direct sound radiated from the test assembly only and is independent of reflections from room surfaces which are governed by the properties of the receive room. If this assumption holds, the measured impact sound pressure levels need not be corrected for receive room properties and the impact sound pressure levels measured in rooms of different size and furnishing conditions can be compared directly.

In the first part of this paper the influence of the receive room volume and reverberation time on the measured sound pressure level are investigated experimentally. All measurements were carried out in the NRC/IRC Flanking Facility unless otherwise indicated. The facility consists of an outer shell with high sound isolation. The space inside the shell is divided by 4 floor and 8 wall assemblies into eight rooms with four rooms on two floors. The walls and floors under test are connected as in real buildings. This allows measuring direct sound transmission between adjacent rooms through their common partition as well as flanking transmission between any room pair through building elements that are coupled at common junctions, or the apparent sound transmission which is a combination of direct and flanking transmission. However, measures were taken to suppress flanking sufficiently so that the data presented here are reasonable estimates of direct transmission through the floor-ceiling assembly. The rubber “ball” was used in this study because it is easier to use than the “bang

machine". The results and findings given in this paper are also valid for both the bang machine and ball impact sources because the test procedure and signal processing are identical. For each test the ball was dropped at nine positions (one in the centre, 2 on each room diagonal and 4 in-between the points on the diagonals) in one of the upper rooms. The facility is equipped with an automated data acquisition system and a robot in each room moves a microphone to nine fixed measurement positions and the sound pressure level is measured in all 8 rooms simultaneously.

3. RECEIVE ROOM VOLUME STUDY

Measurement setup

For the receive volume study the test specimen was a common North-American wood frame floor and wall assembly. On both levels of the facility, all walls had 2x4-wood framing with a stud spacing of 400 mm on centre. The wall cavities were filled with fibre glass batts and on one side a double layer of gypsum board was directly attached to the framing whereas on the second side a single layer of gypsum board was mounted on resilient channels. The floors were framed with wood I-joists spaced 400 mm on centre with single layer of 19 mm OSB subfloor. The ceiling consisted of two layers of 16 mm gypsum board mounted on resilient channels attached to the bottom of the floor joists and floor cavities were filled with fibre glass batts.

Three test were carried out and the receive room volume was systematically changed between the tests by simply removing the gypsum board leaves and the cavity absorption of partition walls between the room directly under the source room and adjacent rooms on the lower level. The impact sound pressure level in each of subsequently larger receive rooms is the average of two or three rooms respectively. Fortunately, by removing the walls only the volume was increased and the change of the reverberation time was negligible because the sound absorption in this facility is mostly due to absorption by facility surfaces forming the room boundaries and the surface to volume ratio of the rooms was comparable. Hence, the measured change of the impact sound pressure level can be related directly to the change of the room volume from 43.7 m³ to 81.4 m³ and to 115.8 m³.

Measurement results

The impact sound pressure levels measured in the three receive rooms of different volume are presented in Figure 1a. Since reverberation time was equal for all measurements, the graphs clearly indicates a bias associated with receive room volume – impact sound pressure level decreases with increasing receive room volume. The effect is largely frequency independent. The difference of the results of test 1 (receive room volume: 43.7 m³) and test 2 (receive room volume: 81.4 m³) is about 3 dB suggesting the level scales with the ratio of the volume.

Thus, the correction given in Equation 1 which is applied in ISO 140 to adjust steady state signals of situation S1 to situation S2 is applied to the measurement results. The last term on the right hand side is neglected, since reverberation time T is similar for all room volumes.

$$L_{S2} = L_{S1} + 10 \cdot \lg\left(\frac{V_1}{V_2}\right) - 10 \cdot \lg\left(\frac{T_1}{T_2}\right). \quad (1)$$

The adjusted impact sound pressure levels are shown in Figure 1b and the difference of the impact sound pressure levels is much less than 1 dB in most of the frequency range.

Thus, impact sound pressure levels measured according to JIS 1418-2 depend on the volume of the receive room and measurement results measured with grossly different receive volumes must be corrected according to Equation 1 before comparison.

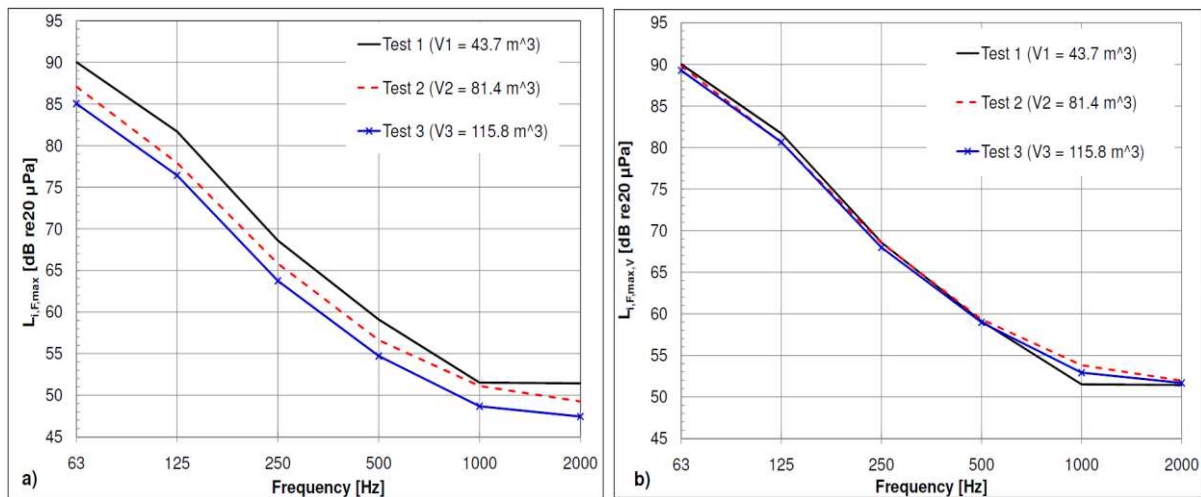


Figure 1. Change of impact sound pressure levels with receive room volume -
a) measured levels, b) levels normalized to V_1

4. RESULTS OF RECEIVE ROOM ABSORPTION STUDY

Measurement setup

During the absorption study a test specimen that is more typical of Japan was installed in the test facility. In this case all walls had a 2x6 wood framing with a stud spacing of 455 mm on centre. The cavity between the studs was filled with Japanese fibre glass batts and on both sides a single leaf of gypsum board was attached directly to the frame. The floor assembly was framed with 2x10 scabbed solid wood joists spaced 455 mm on centre and the subfloor was made out of a double layer of 16 mm plywood. The ceiling consisted of a double layer of gypsum board having a total thickness of 36 mm that was directly attached to separate 2x6 ceiling joists and the floor cavity was filled with fibre glass batts.

During this study the impact sound pressure level was measured twice between the same room pair. For the second measurement several 50 mm thick foam panels were placed on the floor and on facility walls of the receive room to increase the sound absorption and to shorten the reverberation time, especially in the mid and high frequency range. Unfortunately, the absorbers were not very effective in the low frequency range, and it was not possible to use thicker absorbers because movement of the microphone positioning system limited the available space in the chamber.

Measurement results

Figure 2a shows the measured impact sound pressure levels, while Figure 2b shows the reverberation time, T , for the two absorption conditions. The measured impact sound pressure level $L_{i,F,max}$ is much lower in the mid- and high frequency range where reverberation time T of the situation with absorbers is much shorter. Thus, the assumption that the measured $L_{i,F,max}$ is independent of room absorption clearly does not hold. Normalization to both room volume and absorption is necessary if impact sound pressure levels are to be compared. As a first trial, the sound pressure level of Test 2 with absorption was normalized analogously to steady-state sources.

The blue curve in Figure 2a shows the sound pressure level that is normalized according to Equation 1 using reverberation time T of Figure 2b. The normalized results agree well with reference Test 1 in the high frequency range, and of course in the low frequency range where the room absorption did not change. In-between the normalized results overestimate the impact sound pressure level by about 3 dB and hence the simple normalization according to Eq.1 is not ideal.

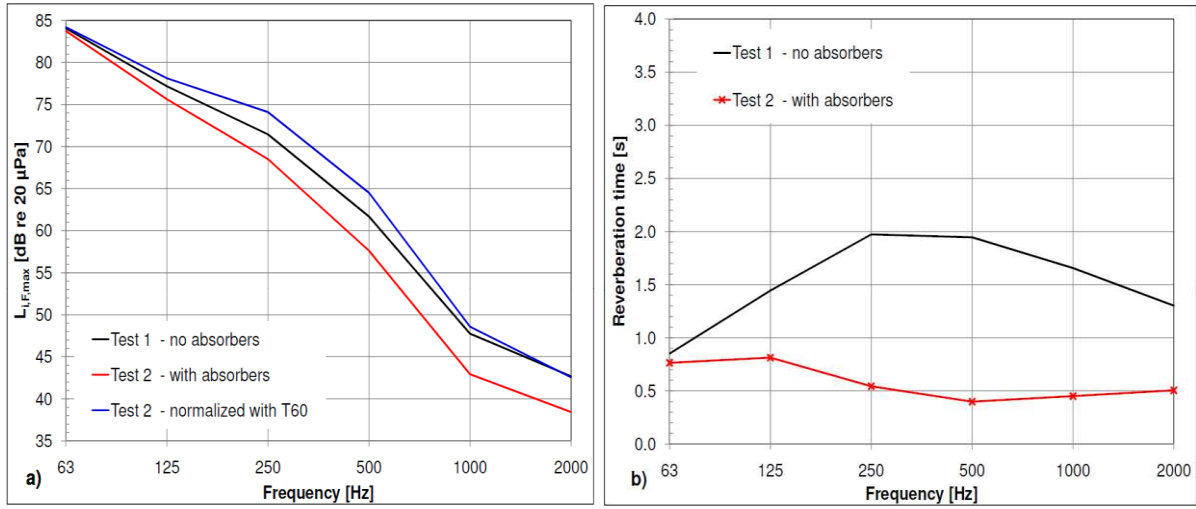


Figure 2. Change of $L_{i,F,max}$ with receive room absorption - a) $L_{i,F,max}$, b) reverberation time T

Theoretical analysis on change of $L_{i,F,max}$ as function of reverberation time, T.

It is further looked analytically into the relationship between $L_{i,F,max}$ and reverberation time, T. The following analysis investigates only the effect of time weighting which is independent of frequency and derived results are valid for all frequency bands. Distortion of the signal due to ringing of the band filters is not investigated further in this paper. It is negligible in the frequency range considered for heavy impact measurement if octave band filters are used as outlined already earlier. Nevertheless, a detailed analysis with derivation of all equations is out of the scope of this paper and presented in Reference [3]. Here only major results are presented and discussed.

F-weighting of an impulse response. The reverberation time, T, is a measure of the time it takes for the sound pressure level in a room after an impulse or noise is switched off to drop by 60 dB. The decay of the sound pressure level in an ideal room is a linear function of time and thus the squared sound pressure p^2 for an impulse at $t = 0$ with peak pressure p_{Peak} is given by Equation 2. Further p^2 is assumed to be zero for $t < 0$ before the impact.

$$p^2(t) = p_{Peak}^2 \cdot e^{-\ln(10) \cdot \frac{6}{T_{60}} \cdot t}, \quad \text{for } t < 0 \quad (2)$$

In general, time-weighted levels are a running average of a time variant signal. The time-constants try to simulate the reaction of the human hearing on noise events with the display of the sound level meter. F(ast)-weighting is originally used for noise events of constant and slowly changing amplitude, but it was found that it is also suitable for short impulses. The time constant RC is 125 ms for F-weighting.

Since early level meters had analogous circuits, time weighting is derived from RC-averaging circuits. The impulse response function $h(t)$ of the exponential time-weighting filter is given in Equation 3 for $t \geq 0$ and $h(t)$ is also zero for $t < 0$.

$$h(t) = \frac{1}{RC} \cdot e^{-t/RC} \quad \text{for } t \geq 0 \quad (3)$$

The F-weighted squared sound pressure p_F given by Equation 4 is the result of the convolution of the input signal given by Equation 2 with the impulse response function of the exponential-time weighting of Equation 3. The convolution integral can be solved analytically after the limits of integration are adjusted appropriately. p_F is given by Equation 5 for $t \geq 0$ s as

function of the peak sound pressure p_{Peak} , the reverberation time T_{60} , and the time constant RC .

$$p_F^2(t) = p^2(t) * h(t) = \int_{-\infty}^{+\infty} p^2(\tau) \cdot h(t - \tau) d\tau \quad (4)$$

$$p_F^2(t) = \frac{p_{\text{Peak}}^2}{1 - 13.82 \cdot RC \cdot T^{-1}} \left(\exp\left(-\frac{13.82}{T} \cdot t\right) - \exp\left(-\frac{1}{RC} \cdot t\right) \right) \quad (5)$$

The instantaneous F-weighted level L_F of synthetic impulse responses with T ranging from 0.05 s to 12.8 s are calculated according to Equation 5 and presented in Figure 3. The dashed red line indicates the linear peak level L_{Peak} of 60 dB that is equal for all room impulse responses at $t = 0$ s because p_{Peak} is set to be 20 mPa. On the other hand the F-weighted levels are all smaller than L_{Peak} . The maxima $L_{F,\text{max}}$ occur with some time delay and both, $L_{F,\text{max}}$ and its time delay increase with reverberation time. The time delay indicates that $L_{F,\text{max}}$ takes into account the direct wave front from the source but to some degree also early reflections that are attenuated by the room absorption. Hence, $L_{F,\text{max}}$ depends also on T of the considered room. The slopes of the decay after $L_{F,\text{max}}$ are much less steep than the initial increase for all graphs. For T of about 1.8 s and longer the decay rate of the level is due to the room impulse response, whereas for shorter T the decay rate is equal and governed by the F-weighting filter.

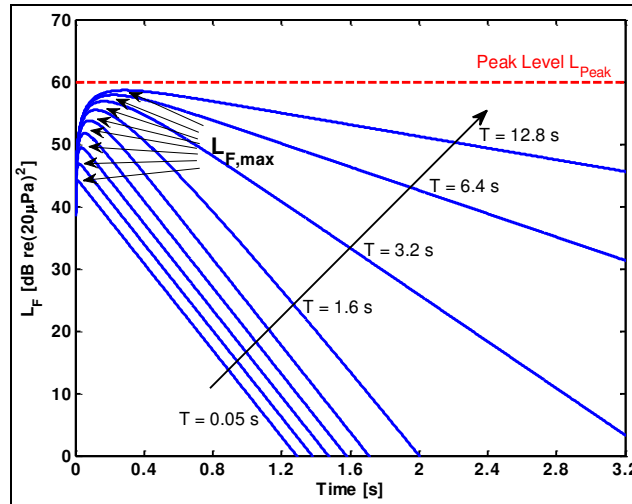


Figure 3. Instantaneous F-weighted sound pressure level L_F of ideal impulse responses with reverberation times T from 0.05 s to 12.8 s

The graphs in Figure 3 show clearly that exponential time-weighting is derived from RC-circuits. Charging and discharging of a capacitor smoothes and delays the actual change of the voltage. Analogously to the sound level, if the voltage is not applied long enough the capacitor will not be fully charged and hence the peak voltage will not be reached.

$L_{F,\text{max}}$ as function of reverberation time, T . The location and value of $L_{F,\text{max}}$ is the maximum of Equation 5 that can be determined analytically. The analytical relationship between $L_{F,\text{max}}$ and L_{Peak} is given in Equation 6 for an ideal sound field.

$$\Delta L_{F,\text{max}} = 10 \lg \frac{p_{F,\text{max}}^2}{p_{\text{Peak}}^2} = 10 \lg \left(\frac{1}{1 - C_T^{-1}} \cdot \left(C_T^{(1-C_T)^{-1}} - C_T^{-(1-C_T)^{-1}} \right) \right), \text{ with } C_T = \frac{T_{60}}{13.82 RC} \quad (6)$$

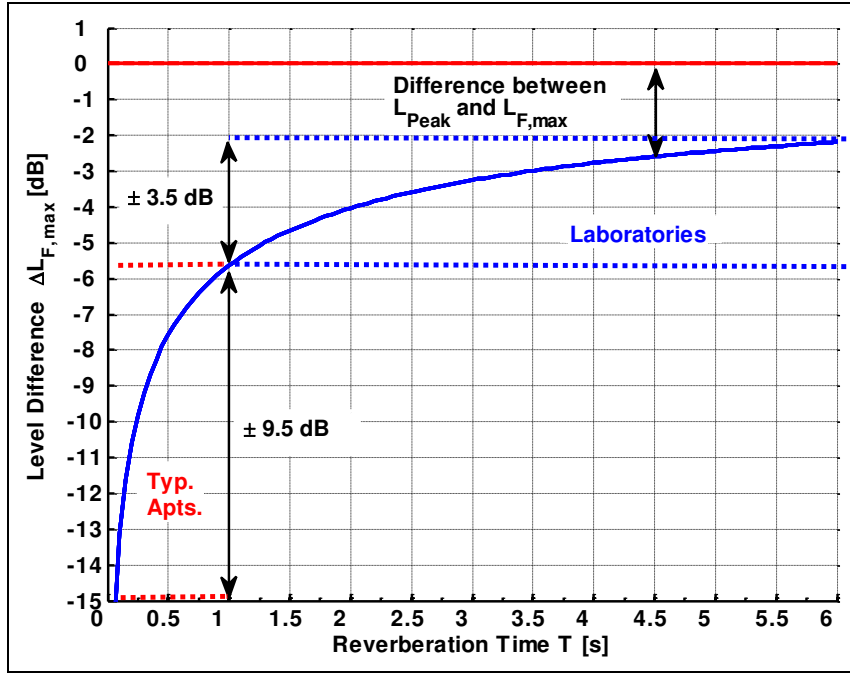


Figure 4. Difference of L_{Peak} and $L_{F,max}$ of ideal impulse responses as function of reverberation time T

Equation 6 is plotted in Figure 4 for typical values of T and $\Delta L_{F,max}$ has only negative values because for an impulse $L_{F,max}$ is always smaller than L_{Peak} . The gradient of $\Delta L_{F,max}$ is greatest for room impulse responses with very short reverberation times and even approaches $-\infty$ for $T \rightarrow 0$. For long reverberation times the gradient of $\Delta L_{F,max}$ is smaller and $L_{F,max}$ approaches asymptotically L_{Peak} for $T \rightarrow \infty$.

Ranges for T in typical rooms are marked in Figure 4, too and in a furnished North American living room it is usually in the range from 0.2 s and 1 s in all frequency bands [4]. In this range $L_{F,max}$ has a spread of about 9.5 dB and thus, the measured heavy impact sound pressure level $L_{i,F,max}$ depends on the reverberation time, T of the receive room. In laboratories the rooms are unfurnished with hard wall and floor surfaces. Although the range of T is much bigger - usually between 1 s to 6 s - the range, in laboratories the spread of $L_{i,F,max}$ is only 3.5 dB.

Thus, the influence of room absorption is more important for heavy impact sound pressure measurements in furnished apartments than for measurements in laboratories. However, results measured in laboratories with long reverberation times can not directly be applied to predict sound isolation in a building situation. Heavy impact sound pressure level might be grossly overestimated – by up to 13 dB going from $T = 6$ s in the lab to $T = 0.2$ s in the field - if room volume is kept equal and only room absorption is significantly increased.

Adjustment of $L_{F,max}$ to room condition

The full term for adjustment of $L_{F,max}$ to a particular room size or furnishing condition is given by Equation 7. The volume term is equal to Equation 1 for steady state levels, but the term $Corr_T$ for the adjustment of the reverberation time can be derived from Equation 6 and given by Equation 8.

$$L_{i,F,max,S2} = L_{i,F,max,S1} + 10 \lg \frac{V_1}{V_2} - 10 \lg (Corr_T) \quad (7)$$

$$Corr_T = \frac{1 - C_{T2}^{-1}}{1 - C_{T1}^{-1}} \cdot \left(\frac{C_{T1}^{(1-C_{T1})^{-1}} - C_{T1}^{-(1-C_{T1}^{-1})^{-1}}}{C_{T2}^{(1-C_{T2})^{-1}} - C_{T2}^{-(1-C_{T2}^{-1})^{-1}}} \right), \quad \text{with } C_{Tj} = \frac{T_j}{13.82 \cdot RC} \quad (8)$$

Again the results of Figure 2 are used to assess the accuracy of Equation 7 and raw data as well as the adjusted are presented in Figure 5. The agreement of $L_{i,F,max}$ without absorbers to the adjusted results with absorbers is very good in the low frequency range below 1000 Hz that determines the single number rating for lightweight assemblies. The difference is much less than 1 dB in this frequency range whereas it is slightly bigger than 1 dB above.

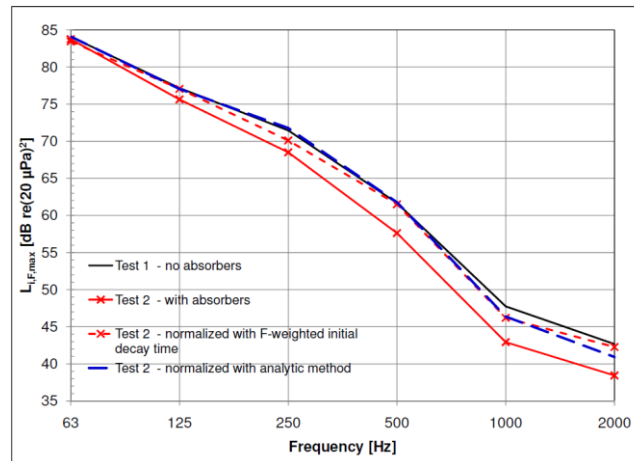


Figure 5. Adjustment of impact sound pressure levels to receive room sound absorption

5. CONCLUSIONS

The maximum F-weighted sound pressure level $L_{i,F,max}$ is dependent on receive room volume and receive room absorption. Thus, an assumption implicit to JIS 1418-2 does not hold. The important consequence is measurement results from different test facilities or measured in dwellings with different size and furnishing conditions cannot be compared directly. Further, it is shown that the simple normalization according to ISO 140 for steady state sources is only valid for the room volume. Normalization using the reverberation time, T , and this method will fail and will usually overestimate the effect of the room absorption. A theoretical analysis on the F-weighting of an ideal room impulse response with arbitrary reverberation time, T , revealed that the $L_{i,F,max}$ is measured with some time delay after the peak level. Thus, $L_{i,F,max}$ takes into account the besides the peak level due to the direct sound wave from the impact also the early reflection that depend on the absorption in the room. $L_{i,f,max}$ is indeed a function of reverberation time, T , the change is not linear and for short reverberation times much greater than for longer ones. Based on the derived equations a new correction term for the reverberation time is introduced in this paper and validated for a single situation. The new normalization method for $L_{i,F,max}$ is very useful to compare results from different facilities or to predict the performance of an tested assembly in the field to achieve a cost effective building design.

REFERENCES

- [1] H. Takahashi, H. Yasuoka “Experimental study on relating between sound absorbing material and floor impact sound in laboratory”, Proceedings of INCE-Japan, 2006
- [2] S. Hirota, H. Suzuki, M. Tanaka “Study report on sound insulation performance between upper and lower floors with ceiling crawl space of wood frame construction”, The Third (2006) Tsuboi Memorial Research Grant, March 2007.
- [3] S. Schoenwald, B. Zeitler, T.R.T. Nightingale “Influence of receive room properties on impact sound pressure level measured with heavy impact sources”, NRC-IRC Research Report 303, 2010
- [4] Bradley, J.S. “Acoustical measurements in some Canadian homes”, Canadian Acoustics/Acoustique Canadienne, 14, (4), pp. 19-21, 24-25. 1986