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Uncertainties in standard impact sound measurement and evaluation procedure applied to light weight structures

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ABSTRACT

A three year research programme has recently started in Sweden, aiming at improving the mutual connection between the perceived sound, vibration and springiness and their corresponding measured values in lightweight structures. The main goal is to describe new objective measures of assessing the acoustic quality, with the expected result that the experienced sound, vibration and springiness are not dependent of structural bearing system in the building any more. The consequence of new methods will be that various structural systems within one certain sound class in a classification scheme will provide fairly equal evaluation with regard to subjective response. The research programme, *AkuLite,* is divided into seven work packages (WP). Initial results from one work package (WP 4), related to current subjective and objective field data are presented in this paper. The aim of topical part of the study is to investigate the liability of measurements results and evaluation procedure when those are carried out in accordance to ISO 140 and ISO 717. It involves an initial inventory and analysis from objective measurements, according to ISO 140, performed on light weight structures on the field by various consultants in Sweden. The study considers principal problems with current standards, affecting each operator performing field measurements in light weight structures and thereby impacting the final result quality. Typically, the measured sound pressure level and the reverberation time differ a lot in low frequencies, compared to heavy structures. The measurement result (distribution) between various measurement positions is rather random in the low frequency region, i.e. there is no typical pattern for light weight structures in general. The complexity of different light weight structural bearing systems and their sensitivity in the low frequency range requires a more rigid description of the measurement and evaluation procedure. The lack of objective sound and vibration data below 50 Hz is also a problem since subjective disturbance often emanates from this frequency range.

INTRODUCTION

Considering light weight floor structures it is a well known fact that the measurement methods and the evaluation methods for impact sound insulation according to ISO 140-7 [1] and ISO 717-2 [2] suffers from shortcomings [3, 5]. The measurement results do not exhibit single number quantities which correlate to the subjective evaluation sufficiently for any arbitrary structural bearing system. Additionally, it is not clear whether the measurements itself are distinct enough, in particular in the low frequency third octaves (< 100 Hz) and their influence on the measurement results.

In Sweden a new research programme recently started. It is abbreviated *AkuLite*, and involves a three year research programme and interest a broad spectrum of universities and industrial partners. The research programme focuses on sound, vibration and springiness in light weight structures and aims to state new measures for evaluating sound insulation (impact sound insulation in particular). To reach the goal the work is divided into seven Work Packages where each research partner is responsible for one Work Package. The seven Work Packages are as follows:

- WP 1 – Subjective experience of sound, vibrations and Springiness – Method development involving laboratory and field studies
- WP 2 – Physical models for structure borne noise sources – Method development
- WP 3 – Calculation methods for components, systems and entire buildings – Method development and simulation
- WP 4 – Current subjective and objective data – Inventory and analysis (present study)
- WP 5 – New measurements focusing on low frequencies and coupling between sound and vibrations – Method development, data collection and analysis
- WP 6 – Correlating data from subjective and objective evaluations – Compiling analysis

- WP 7 – Requirements for sound insulation, vibration and springiness and their entire effect – Results

In this paper some initial results from an investigation within WP 4 is presented, focused on the liability of impact sound insulation measurements and belonging evaluation procedure carried out on light weight structures in multi storey residential buildings. The investigation is based on current data available at consultants in Sweden. The measurements and evaluation of single numbers of impact sound insulation are performed as stated in ISO 140-7 [1] and ISO 717-2 [2] respectively.

These standardized measurement and evaluation methods were developed during a period when the dominating structural materials were heavy (i.e. concrete, bricks etc.) and multi storey houses with light weight structures were not even in building contractors mind, and wooden structures were not even allowed due to fire resistance regulations. In the early 1990's this changed and it became permitted to use wood as structural bearing material for multi storey residential buildings in Sweden and this became the starting point of a new development of light weight structural bearing systems for multi storey family houses. The interest of using light weight structural systems is increasing all over Europe.

Present work is made in order to understand if current measurement procedures performed by professional consultants fulfil the need of accuracy when applied to light weight structures. Some doubts are raised and need for further investigations are proposed prior to use these standardized measurements for further studies in *AkuLite*. Applying current ISO measurements on light weight structures involve new problems and as new building structures develop, it has become obvious that it is far more complex than it appears to be for the measurement performers. There are certain problems appearing in the low frequency region and it involves: (i) liability of reverberation time measurements in low frequencies, (ii) averaging procedure regarding reverberation time in the low frequency region with respect to room volumes, (iii) averaging procedure regarding level measurements with respect to room volumes, (iiii) normalization or standardization procedure, (iiiii) optimized reference curve shape. Adding, lack of information of the constructions complete build up (due to complexity of light weight structures) and scarce available data below 50 Hz, increase the difficulties.

BACKGROUND

Light-weight structures differ significantly from traditional heavy structures from an acoustical point of view. The frequency content of sound originating from a structural impact on a light weight structure distinguish a lot from structural impact on a heavy concrete slab, as shown in Figure 1. In this figure two measured impact sound level curves are presented, one emanating from a light structure and one from a heavy structure. The light weight structure is a wooden floor construction using both a floating floor and a resiliently mounted ceiling. This particular floor construction was earlier measured in the field and was then proved to fulfil the impact sound requirements of the Swedish building code (BBR) [9]. The heavyweight floor is a homogeneous concrete slab with 160 mm thickness. The top surface (floor covering) of both floors was 16 mm parquet on 3 mm resilient underlayer. These two particular measurement results can be directly compared without correction to equal reverberation times or absorption area since both emanates from laboratory measurements using the same receiving room. Moreover, the two floors have the same evaluated impact sound level according to ISO 717-2 if the $C_{I,50\text{-}2500}$ term is included.i.e.

$$L_{n,w} + C_{I,50\text{-}2500} = 52 \text{ dB},$$

which would fulfil the minimum requirement in the Swedish national building code [9] if they represented field values. The characteristics of these impact sound pressure level spectra are quite different since the concrete floor structures result in higher frequency sound (high levels above 200 Hz) while the wooden floor structures result in lower frequency sound (high levels below 50 Hz).

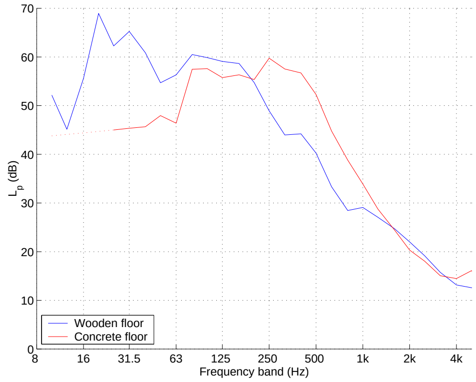

Figure 1: Impact sound pressure level measurements from laboratory tests performed on solid concrete (160 mm), red line, on wooden floor structure, blue line.

Measured sound pressure levels from a field project is shown in Figure 2, where spectra due to tapping machine excitation is presented for 8 rooms in the same building in the frequency range, 8 Hz - 2.5 kHz. From the impact sound curves in Figure 2 it is evident that the highest sound pressure levels are found at frequencies below 100 Hz, and for many rooms the highest sound pressure levels are found below 50 Hz. This is important since the single number value, $L_{n,w} + C_{I,50\text{-}2500}$, is an energetic sum of all included third octave bands, i.e. the frequency bands with highest sound pressure levels influence the single number value the most.

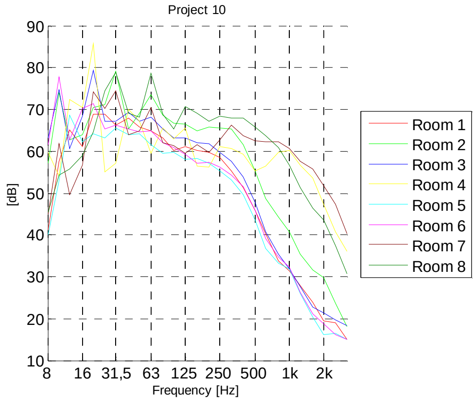

Figure 2: Typical levels from different rooms in one project in a building with light weight structure. The highest levels appear in general below 50 Hz.

One certain problem that appears at high levels of low frequency sound is that the human ear is more sensitive to level differences in the low frequency domain. Once the signal appear a sound pressure level difference in 3-5 dB is perceived as a doubling of the sound level for the lowest frequencies, compared to 1000 Hz where a 10 dB difference is perceived as a sound level doubling [4, 7]. One very common misunderstanding is that human hearing only is active for frequencies higher than 20 Hz. As has been shown in some papers [4], human ears may work all way down to 1 Hz. Figure 3 shows isophon curves down to 3.15 Hz. Studying the isophon curves from ISO 226 [7] it is important to note the 20 Hz value is an extrapolation of values at higher frequencies. However, from Figure 3 it is evident that the actual isophon curves at frequencies lower than 25 Hz do not have as steep slope as indicated by the ISO 226 curves. It is also obvious when studying the measured impact sound levels in Figure 1 and Figure 2 and compare those levels to the levels in Figure 3, that it is most likely that the signal exceed the hearing threshold, even with the impact sound machine as a sound source. What happens then when humans are walking or children are jumping?

Where does the misunderstanding that human hearing stops at 20 Hz come from? In studies of low frequency hearing it is often mentioned that the subjective impression of the sound stimulus changes significantly somewhere between 15 and 20 Hz. One of the main differences is that the concept of pitch is lost at lower frequencies, i.e. a sinusoidal stimulus at 10 Hz is not heard as a tone but as an amplitude-modulated rumble.

However, the impact sound pressure level spectra using the tapping machine may not be the only reason why the subjective perception differs from the measured results. Concrete floor structures are homogeneous while wooden floor structures are more complex, constructed out of joists and beams. The structural system differences also lead to different structural losses which probably can affect the subjective impression. Furthermore, the complexity of common light weight structures makes the practical construction more difficult and thus building errors happen more likely, if the process is not fully controlled. This may result in high uncertainties of the impact sound pressure measurements with respect to where the tapping machine is placed. If it is placed direct over a beam the vibrations can be lead straight to the receiving room compared to when it is placed between beams since there is no strong path from the tapping machine to the receiving room.

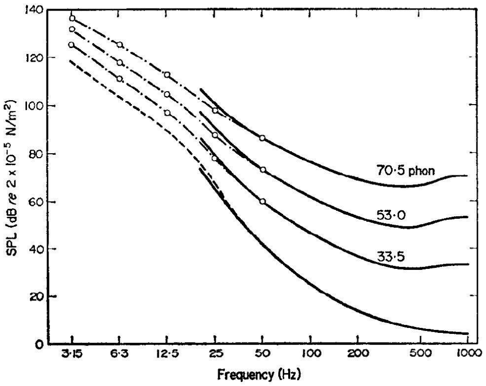

Figure 3: The phon curves extended to very low frequencies (from [4]), describing how the human ear perceives the sound pressure level of different frequencies.

One of the main shortcomings of the ISO measurement methods is the impact source itself. It has been argued in numerous papers that the ISO tapping machine does not resemble the most common sources of structure borne sounds, i.e., human walking, dropped objects, rattling doors etc [10,11]. The shortcomings are related both to the source admittance and that the tapping machine give mainly force excitation in the normal direction, while footsteps include multidirectional excitation [10]. Many attempts have been made to replace the ISO impact machine or to combine it with a heavier sound source which would produce a sound corresponding to more typical footstep impacts on the floor structure. However, in spite of all shortcomings, there are advantages to retain current impact source since it is simple and easy to use for consultants and engineers and it is also established since many decades [3]. One should note that this is not a new argument. The tapping machine was originally designed in the 1930's and its shortcomings became known not long afterwards. For instance there are papers containing severe criticism towards the tapping machine in the 1960's and a similar argumentation was presented in 1965 [10]. In the AkuLite project the choice of source for impact sound measurements will be thoroughly discussed.

Regarding the evaluation method [2], the reference curve is used to estimate weighted single value of the measured impact sound pressure level. As earlier mentioned, applying the method on light weight structures, the result does not correlate to the subjective perception. Therefore, many attempts have been made to define an optimum shape of the reference curve (but still retain the tapping machine). Historically the current reference curve have been criticized many times and alternative shapes have been proposed, at least as early as 1968 [8], where a flat contour was suggested to improve the correlation between objective and subjective results.

The lack of correlation between measured values and subjective judgements, are due to the different characteristics between the impact sound pressure level generated on concrete and light weight floor structures. Similar to earlier research of e.g. Hagberg [3] and Bodlund [5], a further extended brief analysis is included in this investigation in order to confirm whether previous results are emphasized or not, i.e. if the reference curve shape has to take low frequencies into consideration as much as expected.

METHOD

This work is based on studies on several measurements performed according to current ISO standards [1, 2] by consultants in Sweden. The measurements are studied in detail in order to draw conclusions on each parameter included in the measurements, (i.e. reverberation time, level measurements, receiving room volume calculations, normalization etc) and their effect on the final result. Finally, a brief analysis regarding reference curve evaluation is included, by adding five new objects from a Swedish investigation [6] to a previous investigation in [3].

As earlier mentioned, the final results from measurements in buildings erected with light weight structures are normally assumed to be highly affected by the low frequency region, since it does not fulfil the common assumptions in building acoustics theory, i.e. a diffuse and statistical sound field. This implies certain difficulties when measuring and evaluating reverberation time and sound pressure levels at low frequencies. Furthermore, error limits for various measurement aspects (such as receiving room shape and volume) are not established in this frequency region. The results from this investigation points out important parameters in the measurement procedure that might cause errors that affect the final measurement results, in particular when studying light weight structures. The parameters that have been studied regarding error bounds are:

- Reverberation time
- Sound pressure level
- Receiving room volume

Reverberation time measurements

Observant acousticians who have made impact sound measurements in a field situation have probably noticed the large discrepancies of individual reverberation times at low frequencies. To put it in other words: reverberation times can vary a lot in the low frequency region. As previously mentioned there are specific low frequency problems when evaluating the reverberation times, problems which mainly are consequences of not having a sufficiently high modal density in the receiving room. The question arises if the evaluated reverberation times are normally distributed and if it is possible to find error bounds to reverberation time discrepancies. Furthermore, there are huge difficulties to state what is really measured; is it reverberation time in “ordinary manner” as stated in ISO 140-7, or rather the loss factor of the entire building system?

Figure 4 shows the distribution plot from one project where 24 measurement decays are used. The 1/3 octaves between 50 Hz and 400 Hz are presented, the distributions at higher frequencies were very similar. From figure 4 it is obvious that the reverberation times in the lowest 1/3 octave bands differ significantly from a normal distribution. Compared to the distributions at the higher frequency bands in Figure 4 the lowest frequencies show wider distribution, i.e. the error bounds are larger.

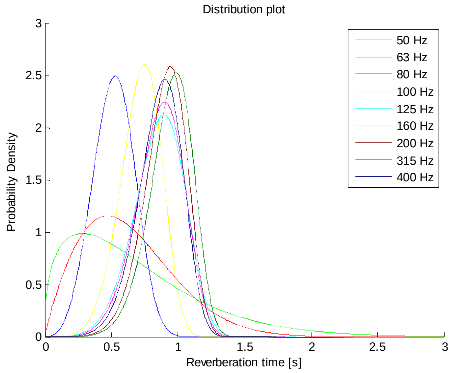

Figure 4: Distribution plot from one project where 24 measurement decays are used. The 1/3 octaves between 50 Hz and 400 Hz are represented.

The reason for the different distribution shape can be searched by studying the data points, for instance using a quantile-quantile plot. Such plots for the 50 and 63 Hz third octave bands are shown in Figure 5 and 6 respectively. In the figures the reverberation time data points are fitted to a normal distribution. If the data would be normally distributed all data points would lie on the straight red line. The solid center section of the red line gives the ± 1 σ confidence interval and the dashed line gives the ± 2 σ confidence interval. It is clear from Figure 5 and Figure 6 that there are some outliers that cause the strong deviation from a normal distribution in the lowest frequency region. The data points would follow a normal distribution much better if these outliers are removed. It is interesting to note that even though the numbers of outliers are equal in both the 50 and 63 Hz band, the outliers are not from the same combination between loudspeaker and microphone position. A simple pragmatic approach to simply omit the individual measurements that introduce the outliers is thus not practically feasible, since only individual third octave bands would be necessary to omit. To rely on a manual choice of which frequency bands that would be omitted, or in other words, which frequency bands that would be included in the evaluation creates a risk of "choosing" the measurement result. A better procedure would be to evaluate the full distribution using e.g. a quantile-quantile plot to identify individual data points that would increase the error bounds and evaluate the expectation value from the modified distribution. However, this procedure assumes that the outliers are results from measurement errors. In practice there are rooms where the reverberation time varies significantly from position to position, e.g., when strong flutter echoes are present. To omit some measurements in such a room would be erroneous. Reverberation times measured in buildings with heavyweight structures, also included for reference in this investigation, show similar patterns in the low frequency region.

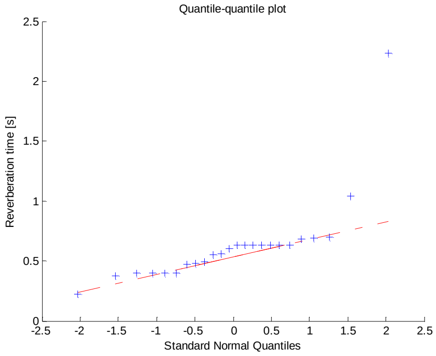

Figure 5: quantile-quantile plot for the 1/3 octave 50 Hz from one project where 24 measurement decays are used. Two typical outliers with long reverberation time are identified

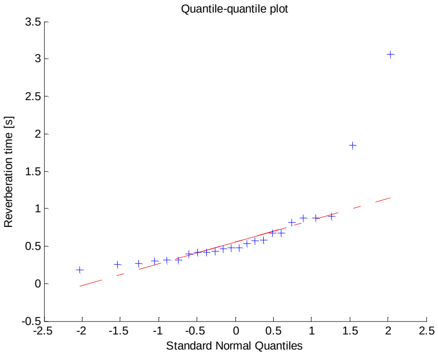

Figure 6: quantile-quantile plot for the 1/3 octave 63 Hz from one project where 24 measurement decays are used. Two typical outliers with long reverberation tmie are identified

At higher frequencies the distribution of the reverberation time measurement results between different positions in the receiving room becomes more normally distributed. This typical example for a light weight structures and uncertainties in the reverberation time measurements can thus be an important error source, due to the effect of normalization to 10 m^2 absorption area or standardization to 0.5 s reverberation time, especially since high sound pressure levels in the lowest frequencies determine the single number value, $L_{n,w} + C_{I,50\text{-}2500}$, and also the degree of disturbance. Furthermore, it is likely to suspect that this skew and wide distribution will retain if the measurements are performed at even lower frequencies.

The size of the term which couples the measured impact sound pressure level to the standardized impact sound level

$$10\log\left(\frac{T}{T_0}\right)$$

can differ with as much as 10 dB in the 50 Hz band evaluated from the minimum and maximum values in Figure 5. This shows that the reverberation time values can affect the standardized impact sound levels, and thus the single number value, significantly.

If the measurement performer is not observant, large errors might appear and the quality of measurement result becomes unacceptable. This could happen even if the results appear to be fine according to the instruments.

Level measurements

One part of impact sound measurements in a building site is to determine the level produced by the tapping machine in the receiving room. In the field situation this is normally made by taking a number of discrete positions well away from the room's boundaries and then averaging these values to one single number. Best fitted distributions of 10 individual equivalent sound pressure level measurements in a receiving room is shown in Figure 7 for the third octave bands between 50 and 400 Hz. Two aspects are visible in the figure: first that the distribution width is comparable for all frequency bands, and second that the distributions are slightly skewed compared to a normal distribution with a longer tail towards lower levels. In other words, it is more likely to receive lower levels than what would be expected from the mean value. The reason for this behaviour is not known, but it might be explained by the allowed location of the microphone positions, away from the boundaries, thus avoiding the higher levels along the room's boundaries. For most frequency bands the skewness is so small that it can be judged not to influence the final results significantly.

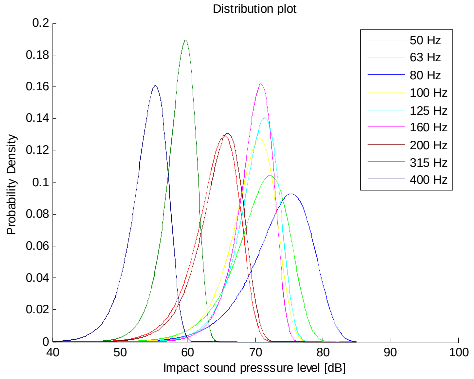

Figure 7: Distribution plot from one project where 10 measurement levels are recorded. The 1/3 octaves between 50 Hz and 400 Hz are represented.

The widths of the distributions are larger than 10 dB for most frequency bands in the figure. The same argument as was used for the reverberation time, i.e., that any eventual error in an individual frequency band can affect the final $L_{n,w} + C_{I,50-2500}$ value can be used for the sound pressure level measurements as well. However, the risks do not seem to increase at lower frequencies in opposition to the reverberation time.

The effect of receiving room volumes

Reverberation time

Another parameter affecting the final result is the receiving room volume. According to statistical acoustics, discrepancies and thus also confidence intervals, should decrease when the room volume increases since the modal density increases with the volume. Of course, this assumes a room approximately homogeneous in terms of absorption and diffusion.

The 95 % confidence interval for reverberation times measured in different room volumes is shown in Figure 7 for selected third octave bands. The confidence intervals for the reverberation time increase for low frequencies as the room volumes increase, quite contrary to the first expectation. This holds for the 50, 63 and 80 Hz frequency bands, while the confidence interval appears to be more stable above these 1/3 octaves. The symbols on the curves are markings of which volumes that are included in this investigation. The straight line is the least squares fitted first order polynomial for each third octave band. The assumption that the modal density is the main factor for measurement precision at lower frequencies, as shown in figure 7, seems to be incorrect. Why the confidence interval increases at low frequencies with room volume is still unknown.

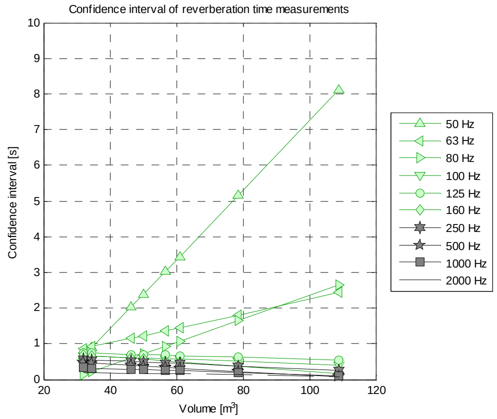

Figure 7: Confidence interval for reverberation time in different frequencies depending on room volumes of the receiving room

Sound pressure level

A similar plot of the relationship between the room volume and the 95 % confidence interval for the measured sound pressure level from the tapping machine is shown in Figure 8. Again it seems like the lower frequencies behave differently compared to higher frequencies, although the differences are not so pronounced as for the reverberation time. The most striking feature of Figure 8 is the decrease in confidence interval at higher frequencies. The behaviour for the third octave bands not shown in the figure was similar.

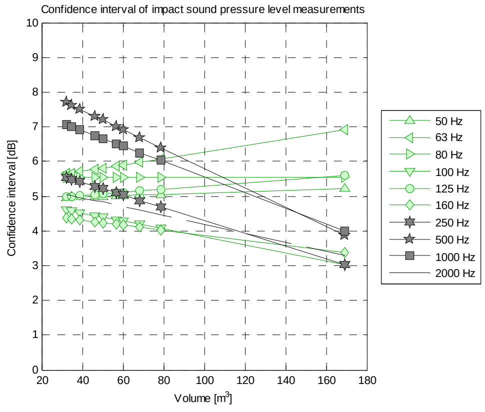

Figure 8: Confidence interval (95 %) for the sound pressure level in different frequency bands depending on room volumes in the receiving room

EVALUATION OF SINGLE NUMBERS

In this paper a number of plots have been shown and mainly general risks for errors or even complete failure are presented. But are the low frequencies annoying in buildings and do the levels normally exceed the hearing threshold and actually create disturbance? At the end, do we need to further investigate and raise the knowledge within this topic? The answer is yes mainly due to the following

1. It is obvious that the statistical methods which constitute basis for measurements and evaluation of single numbers in current standards have shortcomings. This is emphasized when frequency bands outside the "statistical range" determine the single number value. It seems that the reverberation time measurements create certain difficulties.

2. The performers of measurements at consultants working in the field, on site, learn the standard procedure but naturally, they are not aware of all potential shortcomings regarding complex structures and low frequency measurements.

3. The subjective annoyance might appear due to noise levels in frequencies below the frequency range considered in the standards *and* in these 1/3 octaves even more severe, still unknown, evaluation problems might appear.

It is likely that these low frequencies contribute highly to the annoyance. Earlier studies [3, 5] emphazises the need for more focus on the lowest frequencies. This can be further supported by Figure 9 where equivalent level spectra for one of the authors walking and jumping on a floor which was measured to $L_{\mathrm{n,w}} + C_{\mathrm{I,50\text{-}2500}}$ = 53 dB. It is clear that for this floor the highest sound pressure levels are found in the region below 20 Hz. Recordings of footsteps of the same person on the same floor construction in a laboratory are clearly audible, which also can be understood by comparing the spectra in Figure 9 with the extended isophon curves in Figure 3. The exceeding of the hearing threshold is not large measured in dB, but the common experience from studies of low frequency hearing is that small level differences can give large differences in subjective impression.

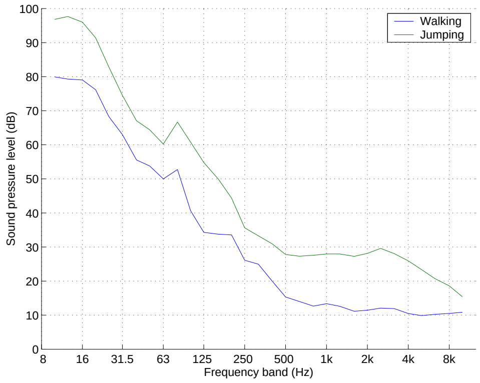

Figure 9: Measured sound pressure level for walking and jumping on a lightweight floor.

In the studies [3,5] field measurements were used and they were compared to interview surveys with inhabitants. Naturally, the results regarding objective measurements according to ISO 140 raises doubts regarding their reliability in low frequencies. Nevertheless, in current study further five objects from a Swedish survey [6] were added to the study [3] in order to extend the number of test objects in the correlation analysis. The results further emphasize the need for more severe studies regarding the low frequency phenomena appearing in light weight structures and how to evaluate the annoyance correctly. Similar to prior studies, present investigation used an optimization procedure to find the reference curve that fitted the subjective data best. Starting with a straight line, this line was tilted in both directions in several steps. The curve was then broken in two segments, each having its own slope. The reference curve was made more and more elaborate by introducing more segments, each with its own slope (uncorrelated to the slopes of the other segments). Up to five segments were used, implying that more than 270,000 curve shapes were tested. The best fitted evaluation curve using linear regression after the extension according to current study is shown in figure 10. It is interesting to note that the reference curve is flat for all third octave bands but the 50 Hz band. Regarding the frequency range where the ISO reference curve is defined, i.e., 100-3150 Hz, the curve agrees with the suggestion by Fasold cited in [8].

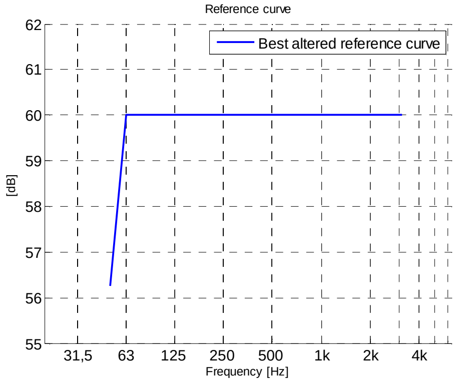

Figure 10: Best fitted evaluation curve after extending the investigation [3] with yet another five building objects from a national survey made by the National Board of Housing Building and Planning [6].

The very steep curve at low frequencies is in accordance with the findings in earlier studies [3] and indicates a need for more scientific and deep studies focused on modern light weight structures and suitable requirements for these structures. The steep curve for low frequencies is itself a warning of "strange behaviour" since it is at the boundary of the evaluation range. Lower frequency bands are probably needed to accurately predict annoyance to a reasonable degree. The optimized curve shape together with the sound pressure level spectrum for walking, shown in Figure 9, emphasizes that high frequencies probably do not affect the final single number evaluation.

CONCLUSIONS

Some major conclusions, or rather proposals for further investigations within WP 4 of the project *AkuLite*, might be drawn from this study

1. The reverberation time measurement with regard to averaging procedure is not satisfactory

2. The reverberation time measurements and their effect of the final results for light weight structures needs to be clarified and quantified

3. Room volume effects with regard to reverberation time measurements at low frequencies and effects on the final results have to be clarified.

4. When point 1, 2 and 3 above is more clarified, establish a measurement programme in general but applicable to light weight structures in particular which is more precise in the low frequency region and hence, useful to use as objective input to the future development of new evaluation methods.

DISCUSSION

The results from present study indicate some important aspects. First of all there is a need for a more extensive overview of the measurement methods and the evaluation principles to promote a successful future development of light weight structures in multi storey residential buildings. So far heavy structures are not included in the work presented in this paper, but instead only highlighting uncertainties that could become severe when applied to light weight structures. Nevertheless, it is likely to believe that current statistical methods are acceptable for heavy structures since the single numbers are determined by mid- and high frequencies. However, as the building technique develops towards more complex and light structures current methods and their applicability decrease, since their rating solely is determined by low frequencies. Hence, the lower the annoying frequencies the more difficult just to extend to lower frequency bands frequencies, but retaining the main method.

Accordingly, as long as the building structures are heavy, i.e. homogeneous concrete, the low frequencies could be neglected. However, if the development of new building technique will stay positive the frequencies which really cause annoyance have to be included in the measurements and the evaluation. But to include these, more knowledge is needed and revised standards (both ISO 140-7 and ISO 717-2) are required rather quick.

Present standards might cause high uncertainties due to:

- Reverberation time is not consistent below 100 Hz, see figure 3, 4 and 5, deviations can affect the final result with several dB:s
- The volume of the receiving room can highly affect the final results in the low frequencies, see figure 7
- For light weight structures, low frequencies (sometimes very low) determine the degree of annoyance, i.e. unknown small errors in the measurement and evaluation procedure might cause incorrect evaluation, either better than expected or worse than expected, at present difficult to quantify.

This work will continue during autumn 2010, with the aim at trying to further investigate and also quantify the errors emanating from measurements according to ISO 140-7, for various structural bearing systems due to the parameters discussed in this paper.

There are several additional issues that has to be discussed further in the continuation of the work within WP 4 in the project *AkuLite*

- If using normalized impact sound pressure, is it proper to use 10 m^2 as reference equivalent sound absorption area at low frequencies?
- If using standardized impact sound pressure, is it proper to use the reverberation time 0.5 s as reference reverberation time at low frequencies?
- Is it proper at all to use reverberation time measurements at low frequencies or is it better to state some sort of structural loss factor for different structural bearing systems?
- Trying to quantify at which frequencies and for which structural bearing systems the problems might arise.

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