Building acoustics classification schemes in multifamily residential projects in the USA

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ABSTRACT

In the United States of America (USA), most building codes have lax requirements for airborne and impact sound isolation in multifamily residences, corresponding roughly to Class E or F in the COST Action TU0901 classification scheme. However, there are segments of the market where housing developers are motivated to provide higher levels of sound isolation because occupant complaints due to poor acoustical isolation will reduce the rates that customers are willing to pay. The authors have worked with several large multifamily housing developers to develop separating wall and floor-ceiling assembly designs, and these have been repeatedly modified based on feedback from occupants. As part of the design process, a large number of field and laboratory tests were performed on these assemblies, allowing comparison between acoustical results and occupant satisfaction. Although limited to a subset of housing types and construction methods, an analysis of these tests defines a de facto classification scheme for airborne and impact isolation. The results are compared to existing classification schemes such as the COST action and the International Code Council *Guideline for Acoustics*.

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I-INCE Classification of Subjects Number(s): 51.4, 51.5, 84

1. INTRODUCTION

In most locations in the USA, the building codes have lax requirements for airborne and impact sound isolation compared with many other countries, and some municipalities (e.g. Chicago, IL) have no requirements at all. Merely complying with minimum requirements does not usually result in a satisfactory level of sound isolation, and acoustical designers have traditionally recommended more stringent requirements. Recently, some of this experience has been formalized by the International Code Council in ICC-G2 Guidelines for Acoustics (1), which two additional classes of performance, Acceptable and Preferred, in addition to Minimum. While these are non-binding guidelines, it is useful to have a documented standard.

The authors have been testing and optimizing a floor-ceiling design for one multi-family developer for the previous eight years. The design has been refined and optimized to be mostly acceptable utilizing feedback from occupants and subjective evaluations, while remaining cost-effective and easily constructible. During the course of this process, a large number of field tests were performed, allowing us to examine the relationship between acceptability for this particular assembly type and target market. We have also analyzed this data in terms of the two-rating system of evaluating impact noise isolation that has been previously proposed by the authors.

2. Impact isolation rating methods

2.1 Building code requirements

In the USA, the building code requirement for field (*in situ*) impact testing of floor-ceiling assemblies between residential units is a minimum rating of NISR 45, where NISR is Normalized Impact Sound Rating (2). NISR is similar to ISO rating $L'_{nT,w}$ except that the rating scale is reversed so that higher ratings correspond to better performance (lower noise levels). The two ratings are

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approximately related by $L'_{nT,w}$ = 110 – NISR; the minimum code requirement is therefore approximately $L'_{nT,w} \leq 65$.

2.2 Non-binding Guidelines

The ICC-G2 Guidelines recommend two additional classes, Acceptable and Preferred, with minimum ratings of NISR 52 and 57 respectively. In Europe, the COST Action TU0901 (3) has proposed a classification scheme with six classes. These are summarized in Table 1. The American code minimum corresponds to the lowest class (Class F), while the Acceptable and Preferred classes correspond roughly to Classes D/E and C, respectively. The 110–NISR is also calculated for ease of comparison with the COST Action classes.

Table 1: Impact Isolation Criteria Summary

COST Action TU0901		ICC-G2		
Class	$L'_{nT,50}$, $L'_{nT,w}$	Class	NISR	110–NISR
Class A	≤ 44			
Class B	≤ 48			
Class C	≤ 52	Preferred	≥ 57	≤ 53
Class D	≤ 56	Acceptable	≥ 52	≤ 58
Class E	≤ 60			
Class F	≤ 64	Minimum	≥ 45	≤ 65

2.3 Low frequency impact noise (thudding)

In floors framed with wood joists, thudding from footfalls at frequencies below 100 Hz is commonly considered problematic. The NISR and $L'_{nT,w}$ ratings do not address these frequencies.

The ISO has developed spectrum adaptation terms in part to address this issue. The COST Action limits are defined in terms of $L'_{nT,50} = L'_{nT,w} + C_{I,50\text{-}2500}$, which is the unweighted sum of the impact sound level from 50–2500 Hz. This is claimed to be "more representative of the A-weighted impact levels as caused by walking for all types of floor" according to ISO 717-2 (4). The COST Action notes that this metric is used as it "has emphasis on low frequencies as this is more relevant for subjective assessment."

In North America there is no similar rating system, and frequencies below 100 Hz are not considered in impact noise regulation.

2.4 A two-rating method for evaluating impact isolation

Over the previous two decades the authors have worked to develop a two-rating method of evaluating impact noise, and we summarize our current findings here as there is clear evidence of two independent domains for impact sound. The low-frequency rating to quantify thudding is based on the unweighted sum of the sound pressure level in the 50–80 Hz bands. The rating is called LIR for Low-frequency Impact Rating (5) and is defined so that higher ratings correspond to better isolation.

A separate rating for mid- and high-frequency impact noise does not seem to be necessary as this frequency range is covered by existing NISR or $L'_{nT,w}$ ratings. However, the authors have found that the for high-frequency impact noise such as dropping objects, heel clicks, and dragging furniture, the existing ratings do not perform well in evaluating the performance. Often changes to the finish flooring or sound mats below floating floors causes a large change in the sound level due to these sources, but only a small change to the rating. This occurs when the rating is controlled by noise in the 100–315 Hz bands, which generally does not change with changes in finish flooring or sound mats. This demonstrated in the analysis below. Therefore a new rating called HIR or High-frequency Impact Rating (6) has been developed, which is similar to the existing ratings except that the lower limit of the frequency range is 400 Hz.

2.5 Classifications in a Two-rating Method

Given the two-rating method as described, it still remains to classify floors in the new ratings. The LIR was not based on any previous metric and so was unconstrained. For convenience, the authors chose to define LIR such that ratings of 50, 60, and 70 corresponded roughly to the three classes in ICC-G2. For lightweight floors where the impact noise spectrum is dominated by low-frequency energy, the LIR and $L'_{nT,50}$ are proportional, because the higher-frequency terms do not contribute to the result. The approximate relationship for floors controlled by impact noise below 100 Hz is shown in Table 2. Note that LIR and $L'_{nT,50}$ are not related for floors with significant energy at other frequencies measured as part of the test method. Being uncontrained allows for steps in the LIR to be wider than $L'_{nT,50}$, which is indicated in Table 2 where the LIR step of 10 points is correlated to a step of 5 points with $L'_{nT,50}$.

Table 2: Comparison of LIR and $L'_{nT,50}$, valid only for floors controlled below 100 Hz.

LIR	$L'_{nT,50}$
40	60
50	55
60	50
70	45

The HIR is defined based on the existing reference spectrum for the NISR/ $L'_{nT,w}$, so the level was already defined. Therefore, the question remains as to what are the appropriate limits of classifications of HIR.

3. Testing Results

3.1 Assembly and Revisions

The authors aided in the design and optimization for the floor-ceiling assembly for one multi-family developer. The assembly (see Figure 1) is framed with 2x10 (nominal inch dimensions, approximately 38 x 240 mm) solid wood joists with plywood subfloor sheathing and 90 mm (3.5 in.) batt insulation in the joist cavities. The floor side is finish floor over 25 mm (1 in.) gypsum concrete over 6 mm (1/4 in.) primary sound mat. The ceiling side is one layer of 16 mm (5/8 in.) gypsum board on 12 mm (1/2 in.) resilient channels. Finish flooring was limited to carpet in bedrooms and most living rooms, but hard surface flooring was desired in the living rooms as well.

The original assembly generated excessive complaints and was evaluated by the developer to be completely unacceptable based on their subjective impression and the reaction of the building occupants.

Numerous attempts were made with various products and designs, and realizing the new design involved a large amount of laboratory and field testing, fire testing, and subjective evaluation. The revised assembly had engineered wood laminate flooring, installed on top of a thin foam secondary sound mat, and damped drywall (gypsum board panels made of thinner layers laminated with viscoelastic glue) on the ceiling. At bedrooms, the finish floor was carpet and pad, and the ceiling was regular gypsum board.

The revised assembly was a large improvement over the original, and the client's evaluation was that the improvement was sufficient to allow installation of hard surfaced flooring in all rooms except bedrooms.

It was discovered, however, that installation errors and unapproved substitutions had been made during construction, and the consistency and quality of the installation could be improved. A Quality Assurance program was started, which involved observations of the construction of the assemblies that included a large percentage of the homes.

Source: Maxxon

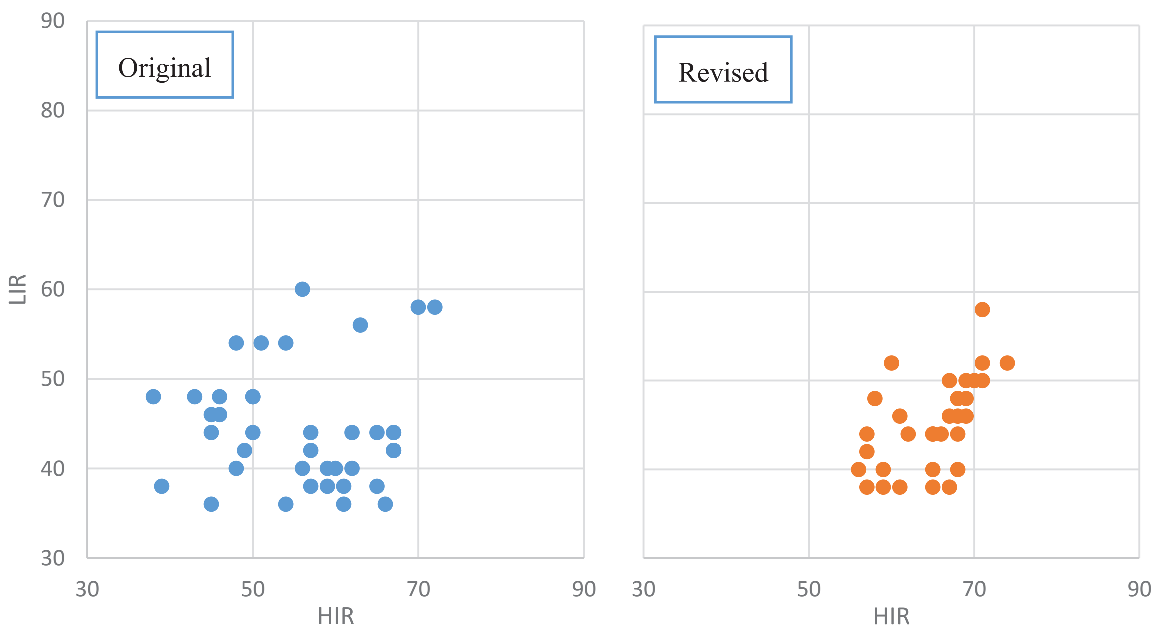
Figure 1: Sketch of the floor-ceiling assembly

3.2 Results

Throughout the process described above, at least 250 field tests were performed on the assemblies in the various stages of development. We separate the testing into three groups. Group 1 is the original assembly, Group 2 is the improved design but with inconsistent construction, and Group 3 is the improved design with the quality assurance program. For comparison, a fourth group of carpeted floors is included. The average ratings are shown in Table 3 and graphed in Figure 2.

Table 3: Average Impact Ratings

	NISR	$L'_{nT,w}$	$L'_{nT,50}$	LIR	HIR
Original	51.9	57.3	58.9	44.5	56.1
Revised	55.0	54.6	58.5	45.2	64.9
With QA	59.8	50.2	55.3	50.5	68.2
Carpet	73.7	31.9	49.3	57.7	82.3



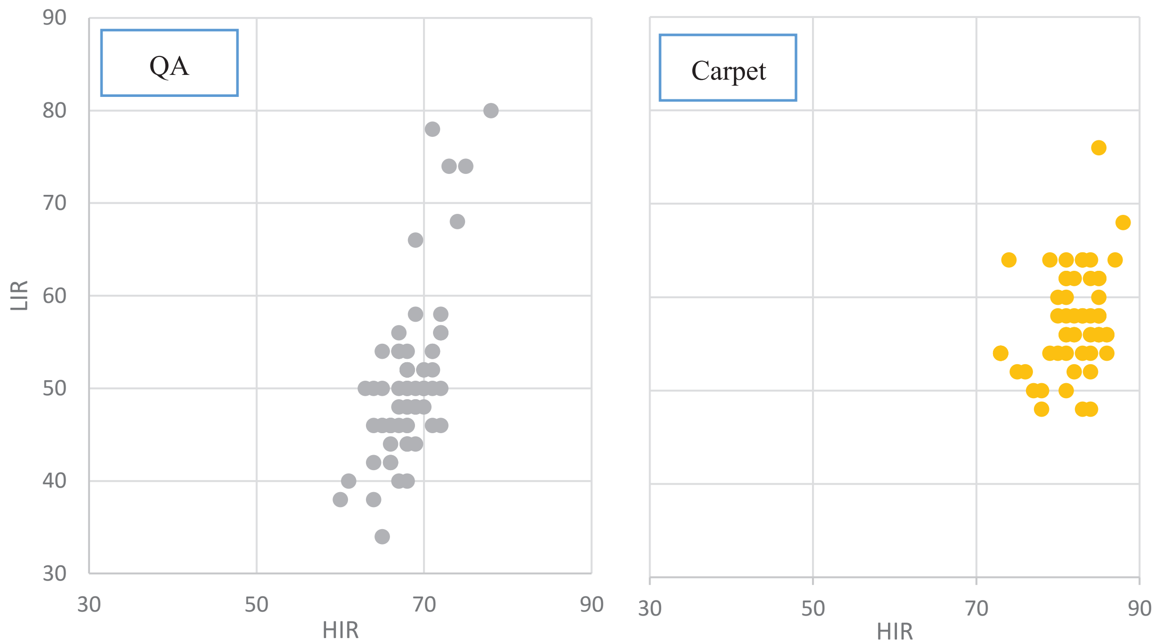


Figure 2: Field Test Results in the Two-Rating System

3.3 Analysis

Overall, the average low frequency performance of the flooring improved by 6 points in LIR and 4 in $L'_{nT,50}$. The resultant performance was a definite improvement, but remained rather average. Low-frequency thudding from footfall remains clearly audible. For this client, building type, and type of tenant, this level of low-frequency performance was acceptable. In other words, the client feels that number of complaints and the rent that can be asked is satisfactory, and the cost to further improve the low-frequency levels are not justified.

In the high frequencies, the original assembly was unacceptable and the ratings were as low as HIR 38. The revised assembly was significantly better, with a 9 point increase in HIR. This assembly was judged to be acceptable to allow hard surface flooring in living rooms. With improved quality assurance, the high frequency further improved by 3 points (12 points higher than the Original), and perhaps more significantly the range of values on HIR tightened considerably, corresponding to the improved quality control. This can be seen in the rightward progression if Figure 2. These floors have very good high-frequency performance, and events such as dragging furniture and footfall in hard-soled shoes are barely audible. The results show not only the importance of the analysis is the HIR domain, but the benefit of performing Quality Control on the resultant acoustical performance.

4. Comparison of Single Number and Dual Number Ratings

The NISR/ $L'_{nT,w}$ improved also, but by a lesser degree of 7–8 points. Further, in the initial step from original to revised assembly, the NISR/ $L'_{nT,w}$ improved just 3–4 points, versus 9 points for the HIR. This clearly demonstrates the advantage of the two-rating method in evaluating floors. As the high-frequency performance of the floor improves, the NISR/ $L'_{nT,w}$ ratings start to be controlled at lower frequencies and start to level off or “max out” meaning that the upward performance is limited by the low frequency effects, which does not provide the correct picture of the improvement in the independent domains.

Figure 3 plots the HIR versus the NISR for the hard-surfaced tests in this study. (The relationship is the same for $L'_{nT,w}$, just the scale on the abscissa would be different.) The HIR=NISR line is plotted for reference. For lower-performing floors, the ratings are essentially identical, which is expected because poor floors will have significantly deficiencies at the higher frequencies. At higher ratings, however, the floors have resilient sound mat products that significantly reduce the level at higher frequencies, and the single-number rating starts to be affected by deficiencies at lower frequencies. Above about a rating of 45, the data points tend to fall above the line, often by a significant amount. In other words, for higher performing floors, the NISR under-represents the isolation, especially at high frequency.

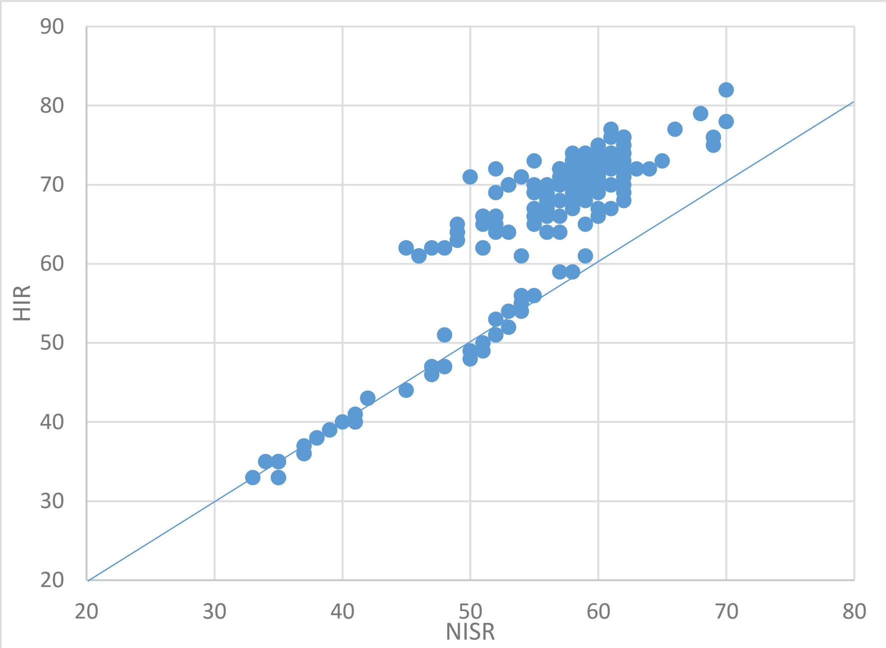


Figure 3: Comparison of HIR vs. NISR

For this floor type, the low-frequencies dominate and the $L'_{nT,50}$ metric is tightly correlated with the LIR. Since the LIR was the lower of the two ratings, one might consider that that was the only rating needed to evaluate the floor. However, this approach does not show the variation along the high frequency axis. The response to impact noise in the two frequency domains are independent. In this case, the average low frequency does not remove the desire of the occupants for improved high-frequency isolation.

Therefore, it is important to be able to evaluate the high-frequency isolation independently of the low frequencies. In this assembly, the finish flooring and secondary sound mats are under continuous evaluation by the purchasing and interior design team and are subject to change. Further, these are rental units, and the flooring will need to be replaced or refreshed periodically. Changing the finish flooring may affect the HIR but will not change the LIR or $L'_{nT,50}$, and it is crucial to be able to evaluate the high-frequency performance even when the low-frequency performance may be considered to be controlling.

Using two metrics not only demonstrates the behavior in both frequency domains, but suggests avenues for future improvements. We might determine that a higher HIR is desired, improve (for example) the sound mat beneath the finish floor, improving the HIR but leaving the LIR rating unchanged. The single rating does not evaluate, suggest, or justify the change, while the two rating system explicitly demonstrates these fundamental variations which allow the designer ability to better focus on needs of occupant and properly address.

5. Conclusions

Based on the project described in the paper and others, the authors have tentatively defined classifications in the two-rating method, shown in Table 4.

Table 4: Tentative two-rating impact isolation classification

Class	LIR	HIR
Preferred	70	65
Acceptable	60	52
Minimum	50	45

The example also demonstrates how the impact noise occurs in two frequency domains and can vary independently in those two domains with changes in the assembly. Using two ratings to separately evaluate the impact isolation in the two frequency domains improves the correlation with subjective reaction. The two ratings system can aid in identifying potential mitigation and predicting its effect. The method also allows the evaluation of products such as finish flooring. Using the two domains to analyze acoustical performance is useful in all aspects of design and evaluation and should be considered as a method of analysis for floor ceilings.

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