Computer Studies of Optimum Classroom Acoustics

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Introduction

The intelligibility of speech in a classroom depends on both room acoustics effects and on the speech-to-noise ratio. Very high quality speech communication requires both optimum room acoustics conditions as well as a low ambient noise level to provide adequate speech-to-noise ratios.

Several studies have shown that a speech–to-noise ratio of 15 dB or more will provide 100% speech intelligibility (where the speech and noise levels are A-weighted levels). Room acoustics has traditionally been described in terms of reverberation time (*RT*) and various optimum reverberation times have been proposed to maximize intelligibility. (Typical recommended *RT* values are from 0.4 to 0.7 s). More modern work suggests that the effects of room acoustics on speech intelligibility are better assessed in terms of early-to-late sound ratios (C_{50}) or Speech transmission Index (*STI*) values. (*RASTI* is a simplification of the *STI* measure).

Adding sound absorbing material to optimise *RT* or to maximize C_{50}, will also affect speech and noise levels in the classroom. Thus to determine optimum conditions for speech, one must consider both speech-to-noise ratios and room acoustics effects. This can best be done in terms of newer measures that combine both effects into a single measure such as useful-to-detrimental sound ratios (U_{50}) or the speech transmission index (*STI*). When these measures are maximized, the particular combination of room acoustics and speech and ambient noise levels provides the best possible speech intelligibility.

Experiments

A typical classroom was simulated using the ODEON room acoustics modeling program. U_{50} values were calculated from the ODEON output combined with speech and noise levels. Speech intelligibility scores were estimated from the calculated U_{50} values.

In the first series of tests the ceiling absorption was varied and the *RT* corresponding to the maximum intelligibility was determined. In the second series of experiments, the location of the sound absorbing material was varied to determine the location that maximized intelligibility.

As seen in Figure 1, the optimum *RT* corresponds to about 0.5 s but a range of *RT* values from about 0.3 to 0.6 s lead to intelligibility scores within 0.5 % of the maximum. Thus, it is not necessary to achieve exactly the optimum RT.

The choice of absorption configuration could increase C_{50} values by as much as 4 dB. Average speech levels could vary by as much as 3 dB with absorption configuration. Only small overall improvements were possible, because the absorption configurations that maximized C_{50} tended not to maximize speech levels. Figure 2 shows the average U50 values for 9 different absorption configurations. These results suggest that previous recommendations for 'optimum' locations of absorbing material may not be of practical importance.

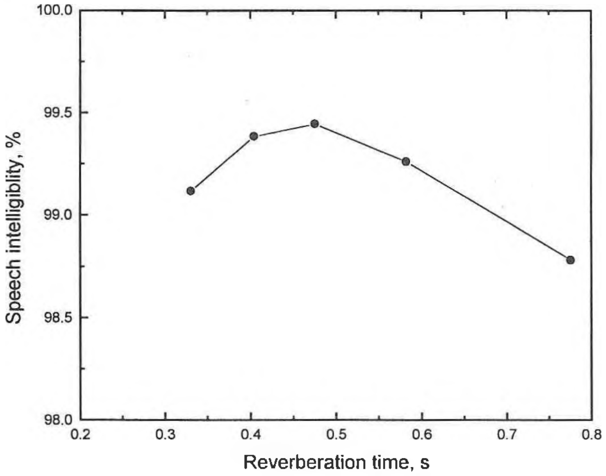

Figure 1. Calculated speech intelligibility versus reverberation time.

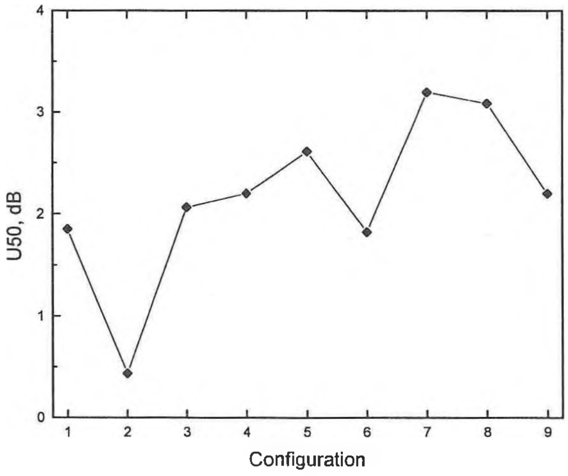

Figure 2. Calculated U_{50} for 9 absorption configurations and omni-directional source.

Sound Transmission Through Floor/Ceiling Assemblies

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Introduction.

The Institute for Research in Construction Acoustics Laboratory has completed the measurement phase of a study of airborne and impact sound transmission through typical floor constructions used in Canadian housing. As well as IRC/NRCC, the project was supported by a consortium including 18 companies or associations from Canadian and US industry. This paper discusses briefly the results found in terms of sound transmission class (STC) and impact insulation class (IIC) ratings made in accordance with the relevant ASTM standards[1,2,3,4]. A more detailed report is available[5].

Types of floors tested.

About 200 different floor variations were included in the study. Joist types included solid wood, steel, wood I-joists and wood trusses. A few joist floors with concrete toppings and three concrete slabs were also tested.

Repeatability

Most important for comparing test results within a series of measurements in a single laboratory is the concept of *repeatability*. This may be defined as the closeness of agreement between independent results obtained with the identical test specimen in the same laboratory with the same equipment and test method by the same operator within a short time period.

Rebuild repeatability may be defined as the closeness of agreement between results obtained on nominally identical test specimens constructed with nominally identical materials with the same test method in the same laboratory. This repeatability is of most relevance where comparisons are being made among floors that were completely rebuilt and represents the highest uncertainty associated with this project.

To estimate *rebuild repeatability*, nominally identical floors were constructed and tested eight times in the laboratory over a period of about 1 year using new materials each time. Four of the STC ratings obtained were 51 and four were 52. Four of the IIC ratings were 45 and four were 46. It was concluded that a change of more than 1 point in the STC or IIC rating could be taken as significant and attributed to a change in the specimen. A change of only 1 is regarded as not significant unless an examination of the 1/3 octave band data shows significant changes.

Major findings.

In the space available it is only possible to give some of the highlights of the report in point form.

- The major factor controlling the sound insulation of a given type of cavity floor is the sum of the masses per unit area of the floor and ceiling layers.
- Of lesser importance, but still significant, are the thickness and density of the sound absorbing material, the depth and spacing of the joists and the spacing of resilient metal channels. Increasing any of these variables increases sound insulation.
- Joist floors without resilient metal channels do not achieve STC 50 in any practical configuration, with or without sound absorbing material in the cavity.
- Using 22 mm deep U-channels to support the gypsum board gave about the same results as using 19 x 64 mm wood furring. Both are markedly inferior to resilient metal channels.
- Changing the joist length had no effect on the sound transmission.
- The tightness of the screws attaching the subfloor to the joists had no effect on sound transmission.
- Increasing the number of screws attaching the subfloor to the joists by a factor of four greater than normal had no effect on sound transmission.
- Attaching the subfloor to the joists using both construction adhesive and nails gave the same results as attaching it using only screws.
- There were no significant differences in STC or IIC between pairs of floors where a 35 mm thick concrete topping was poured on top and allowed to set or where an existing slab was lifted into place on the floor.
- There was no significant difference between a floor constructed using cross-bracing and one using wood strapping. Floors gave the same sound insulation with or without cross-bracing.
- Putting sound absorbing material in the cavity of a joist floor with a ceiling that is not resiliently suspended provides no significant increase in sound insulation.
- Floors with concrete toppings and no additional resilient surface or support for the ceiling, typically get IIC ratings less than 30.
- Differences among types of sound absorbing material are significant but small.

Regression Analyses

Regression analyses of the data collected permit interpolation and extrapolation of the results to cases that were not actually measured. Developing an analytical model would be more satisfactory but requires much more work. This section presents some of the more useful results of the regression analyses.

A regression analysis of all the measured results as one collection of data would not be fruitful. The many variations in construction that are possible have too great an influence on sound insulation and are not easily dealt with using simple linear regression models. Such models would not easily deal with a collection of data including floors having resilient metal channels separating two layers of gypsum board, or floors with and without resilient metal channels. The data were separated into major categories as follows:

- Solid wood joist floors with resilient metal channels directly attached to the joists and with sound absorbing material in the cavity (70 floors),
- Wood I-joist floors with resilient metal channels directly attached to the joists and with sound absorbing material in the cavity (23 floors),
- All cavity floors with resilient metal channels directly attached to the joists and with sound absorbing material in the cavity (110 floors), and