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Sound insulation of building elements at low frequency: a modal approach

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Abstract

In typical laboratory volumes (50-80 m^3) and at low frequencies (50-100 Hz), the acoustic field is non-diffuse due to the presence of source and receiving room modes. Under such conditions, standard sound insulation measurements and descriptors are not adequate to correctly characterize the insulating property of partitions or flooring systems. The «modal approach» allows to evaluate the airborne sound insulation by the determination of modal transmission loss, or modal sound insulation, of a single mode passing through the partition. Proper normalization terms and an extension method to one-third octave bands are also introduced. The same approach is applied to impact sound insulation measurement.

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Keywords: Airborne sound insulation; Building acoustics; Low frequency; Impact sound insulation; Laboratory measurements.

1. Introduction

In recent years an increasing interest in building acoustics measurements at low frequencies (i.e. below 100 Hz, and typically from 50 Hz) has been observed. The consideration of low frequency noise has become more and more important because of the increasing occurrence of sound sources with low frequency content, like technical equipment inside and outside buildings, increased traffic volume and improved video and audio equipment in dwellings, and renewable energy sources [1,2]. Simultaneously, newer multilayer building elements, developed to be cheaper and lighter and possibly to have a better thermal insulation, use to have resonant frequencies below 100 Hz, which become more and more disturbing under such circumstances. Nevertheless, at present time, effective protection systems against low frequency noise are still an open challenge both for researchers and components

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manufacturers. In building acoustics, noise below 100 Hz has been generally neglected up to now, because the actual sound insulation measurement methods require diffuse sound fields. Standard measurements are performed in the frequency range between 100 Hz and 5000 Hz in one-third-octave bands and are not suitable and accurate enough in order to achieve repeatable and reproducible measurements in the low-frequency range (50-100 Hz). Standardized airborne and impact sound insulation laboratories, in which volumes range between 50 m^3 and 80 m^3, are characterized by a non-diffuse field (i.e. wavelengths equal or wider than room dimensions) below the Schroeder frequency, usually around 350 Hz. In any case, for practical reasons, a condition of diffuse field from 100 Hz on is conventionally accepted. Below 100 Hz, acoustic room modes lead to a high spatial spread of sound pressure levels and a high dependence on boundary conditions (modal damping, room volumes, room dimensions). On the basis of this, measurement solutions are needed in order to extend standard sound insulation measurements down to 50 Hz.

2. The modal approach for airborne sound insulation

The standard descriptor of sound insulation, i.e. the sound reduction R, is related to the transmission coefficient τ that is defined as the ratio of the sound power transmitted by the test element to the sound power incident on the test element. Assuming diffuse field, sound reduction is expressed as the difference between average sound pressure levels in source and receiving rooms plus a term depending on equivalent absorption area A. Application of such approach to non-diffuse field condition entails low reproducibility values of sound insulation [3,4] and it is not representative for the correct physical phenomena involved (low modal density, not uniform acoustic field in space and frequency domains). Currently it is not possible to correctly define the incident and transmitted sound power in such modal acoustic field according to the standard approach. Besides, a new sound intensity measurement procedure has been recently proposed in order to achieve low frequencies airborne sound insulation in laboratory [6]. Nevertheless sound intensity approach is subjected to several practical complication, such as the presence of a totally sound absorbing surface on the opposite wall, in receiving room and, at this time, the lack of a standardized calibration procedure of the sound intensity probes. Theoretical background and fundamental equations for calculations are provided by Morse and Jo’s works [7,8].

2.1. The modal sound insulation

As described in [9], the evidence of transmission of source room modes into the receiving room through the partition allows to introduce the modal approach in the evaluation of sound insulation based on a description of modal sound transmission loss, i.e. the attenuation of source room modes passing through the partition into the receiving room. Such evaluation allows to shift from a statistical point of view in terms of average sound pressure levels, typical of diffuse field condition, to a discrete one, focused, in frequency domain, on source room modes and, in space, on the points of highest modal sound pressure levels (corners of rectangular rooms). Such descriptor of sound transmission loss in non-diffuse field can be represented by the modal sound insulation, $D_{modal}(f_n)$ which is defined as difference between the highest sound pressure levels of natural and transmitted source room modes, f_n, evaluated in the corner positions, $\boldsymbol{x_{corner}}$, of source (*chamber 1*) and receiving (*chamber 2*) rooms (Eq. 1).

$$D_{modal}(f_n) = 10\ \log_{10}\left(\frac{p^2_{1,\max}(\mathbf{x_{corner}}, f_n)}{p^2_{2,\max}(\mathbf{x_{corner}}, f_n)}\right) = L_{1,\max}(f_n) - L_{2,\max}(f_n) \tag{1}$$

It is a discrete index as it refers just to source room resonant frequencies and provides an indication of sound transmission loss of a single mode passing through the partition from the source to the receiving room. In addition, resonant frequencies provide information about the resonant half bandwidth Δf_{-3dB} related to modal absorption [10] and are stable in time.