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Assessment criterion for indoor noise disturbance in the presence of low frequency sources

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ABSTRACT

Several studies have presented the effects of environmental noise in and around buildings and communities in which people live and work. In particular, the noise introduced into a building is mostly evaluated using the A weighted sound pressure level (L_{Aeq}) as the only parameter to determine the perceived disturbance. Nevertheless, if noise is produced by activities or sources characterised by a low frequency contribution, the measurement of L_{Aeq} underestimates the real disturbance, in particular during sleeping time.

The international literature suggests methods to evaluate the low-frequency noise contribution to annoyance separately from the A weighted sound pressure level; almost all of the proposed methods are based on exceeding a threshold limit.

This paper tests international criteria, by applying them in real-life indoor noise situations, and then analysing, comparing and contrasting results.

Based on the result of the procedure above, a new criterion consisting of a single threshold is proposed, which simplifies the procedures in case of low-frequency components, but could be used for any situation.

1. Introduction

The existing and consolidated assessment methods of annoyance inside dwellings are widely based on the A-weighted sound pressure level measurement (L_{Aeq}). Nevertheless this parameter leads to an underestimation of the influence of mid (generally over 250 Hz) and low (generally below 250 Hz) frequencies [1–3].

Noise disturbance has increased hugely in the last 15–20 years. Even if traffic noise is generally considered as the first cause of disturbance, both for annoyance or sleep problems, in many cases the source is related to music, people speaking or external noisy machinery. In particular, concerning the first source, weekends have become a very difficult period for inhabitants living close to venues such as clubs, discotheques and pubs. Furthermore, these activities have usually powerful external HVAC (Heating, Ventilating, Air Conditioning), increasing the noise problems at low frequencies.

Moreover, at night the residual noise is generally lower than during the daytime and consequently the disturbance is increased. In many countries, the existing regulations do not provide an objective method able to determine whether music, HVAC or other sources create annoyance in relation to a given moment or period.

Often, the criteria used are fully based on A-weighted sound pressure levels. The A-weighting is based on the peculiar perceptions of the human ear. So using L_{Aeq} level as a mean value or as the difference with background or residual noise could lead to a misinterpretation of the results, as explained below.

The background noise is defined as the L_{90} value; on the other hand the residual noise is the result of a measurement where the noise sources are turned off.

Several measurements throughout the years have shown that the A-weighted sound pressure level was misleading in determining noise disturbance. McCullough and Hetherington [4] show how this parameter underestimates the prediction of nuisance, using a in situ based measurement technique. Jakobsen [5] described how the A-weighted filter overestimates the loudness at low levels at low frequencies. The authors stated that the L_{Aeq} parameter do not give a good estimate of the annoyance. Mirowska [6] as well as Cocchi et al. [7] using both laboratory measurement under strict

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medical protocols and real case studies demonstrated how low frequencies are less tolerated and perceived as more annoying than other frequencies and then the common L_{Aeq} single number methods could not represent the a good subjective evaluation

Though, distorted results are possible and could depend on many reasons:

a. underestimation of structural transmissions at low frequencies,
b. time of day or night when the noise appears,
c. receiver exposure time.

As a matter of fact, if the residual noise is not characterised by low frequencies, the presence of sources with these components leads to a stronger perception [8], especially at night. Therefore it is evident that the single A-weighted sound pressure level cannot be a reliable indicator, suitable to assess whether the disturbance exists or not.

Because of this reason, in this paper a selected number of noise assessment criteria (both single number and frequency analysis) are tested in order to understand and compare their methods. As a result, what was found is that all these criteria do not include many issues such as precise measurements guidelines or punctual and clear measurement spot selection; furthermore they provide very different hearing or assessment thresholds. Then, a proposal for a harmonised criterion is established by combining methods supplied in the literature with those established by the Italian legislation.

The proposed method is to be used in lawsuits, disputes or whenever an objective evaluation is needed. In this study, noise disturbance is considered both as annoyance and sleep disturbance.

2. Literature review

2.1. General studies and soundscape approach

In the last decades many authors have described the sound pressure level risks [9] both outside and inside dwellings. Miedema and Oudshoorn [10] connected annoyance with noise, focusing on transportation noise using DNL and DEN values. Even if this is a very good method, it requires very long measurements and only works for transportation sources. Indeed, it is difficult to apply it to disco pubs, people speaking, HVAC, etc.

More recently, the COST TUD action TD 0804 collected a large number of results obtained by different participants worldwide. Within the published e-book [11], many issues are presented in order to investigate noise and soundscape. The definition of soundscape, using the standard ISO 12913-1:2014 [12], is as follows: "acoustic environment as perceived or experienced and/or understood by a person or people, in context".

In particular, Kang et al. [11] report that over 30% of the EU population is exposed to noise levels above the WHO recommendation; Drever [13] studied the effect of ultra-rapid "ecological" hand dryer on vulnerable groups; Ortiz and Schulte-Fortkamp [14] focused on quite zones; Lercher et al. [15] studied the noise effects on children; Prodi et al. [16] studied the impact of noise on intelligibility in classrooms; Hiramatsu [17] connected noise and soundscape. These studies were very important in order to understand the subjective effect on receivers, but it does not supply an objective method to assess the disturbance.

Soundscape studies approach noise as a "resource" rather than "waste" [9]. In lawsuits or disputes, however, this approach is never used. In addition, it requires people to complete questionnaires regarding their positive or negative feelings towards sounds and noise. In a dispute, these results become difficult to use, as the different parties are not interested in soundscapes, but rather in winning the case.

None of these methods takes into account the façade, airborne and impact sound insulation in buildings because disturbance is measured in the context in which it takes places (noise propagation, time of day and night, etc.). Therefore, in order to evaluate the annoyance of the intruding noise, its characteristics are more important than the way in which it enters the dwelling. Clearly, the sound insulation performance of the building can affect the final perception of the intruding noise [18], even at low frequencies or in the case of impact noise [19,20]. Nevertheless, this relates only to the rating of the buildings [21,22] and not to the evaluation of the intruding noise. In order to reduce disturbance, when necessary, sound insulation can be improved or the noise level of the source can be reduced.

2.2. Single value: L_{Aeq} based techniques

2.2.1. International method: WHO guidelines

The WHO guidelines [23] are frequently used in the acoustical community. They propose health-based limits for night noise exposure stating that noise nuisance exists when the measured L_{Aeq} value inside a dwelling at night exceeds 30 dB(A), with higher limits when short-term measurements or maximum values are considered. Furthermore, it is specified that an external level below 30 dB(A) does not create negative effects on the health of the dwellers, including vulnerable groups such as children. This limit is to be considered as a long-period equivalent level. Interim levels of 40 dB(A) and 55 dB(A) were also proposed where the 30 dB(A) ultimate target cannot be achieved in a short period.

The WHO approach sets maximum thresholds for both inner and outer levels. Noise levels exceeding these thresholds are deemed to disrupt sleep. It was mainly created for traffic noise and it is based on overall levels (L_{Amax} and L_{Aeq}) only. This makes measurements and post-elaboration fairly easy, but does not take into account the mid-low frequencies contribution. The use of a single number value could lead to an underestimation of the noise disturbance since it is the average of every frequency from 20 Hz to 20,000 Hz. Then it could take into account different sources from the studied one(s) and (because it is weighted) it modifies the frequency and though the final evaluation.

2.2.2. Regional methods: Italian methods

As an example, Italian methods are presented, the first is required by the applicable legislation [24] and the second is an agreed but not codified "comparative" system adopted when the actual conditions do not allow the use of the mandatory method. It is sometimes used in court if required by the judge.

The first method consists of the L_{Aeq} measurement and third octave bands analysis with a minimum sampling rate of 125 ms. This is necessary for the investigation of tonal or impulsive events in the measured signal (frequency range 20–20,000 Hz).

The final values need to comply with the mandatory requirements specifying separate limits for daytime and night time. These limits take into account both external and internal acoustic conditions. The outer (*absolute*) values are not to be exceeded and are based on equivalent levels over the whole day or night periods. The inner values (*differential*) are evaluated considering the difference between the environmental and the residual noise (noise source switched off). If the measured L_{Aeq} is greater than the residual noise by 5 dB during the day (6–22) and 3 dB during the night (22–6), then the measured noise is regarded as disturbance. The measurements are based on short-term periods (about 1–20 min for example), with the disturbing source on and off.