# TONAL NOISE IN BUILDINGS: CURRENT PRACTICE IN MEASUREMENT AND ASSESSMENT

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## 1. INTRODUCTION

Within today's buildings, noise sources and humans are often in close proximity, leaving little space for acoustic precautions and noise controls. Avoiding problems during the design stage and mitigating them should they be identified afterward remains an ongoing concern due to increasing occupant demands for space comfort. Audible tones may be generated by a variety of mechanical and electrical equipment. Public sensitivity towards noise has resulted in research dealing with impulsive, cyclic, and tonal characteristics. This paper is a review of the research and guidelines for tones that may be applied towards buildings.

## 2. BACKGROUND AND GUIDELINES

A tone is defined as a sound where most of the energy is concentrated at a single frequency, and is more likely to be detected at low levels. One of the earliest evaluations of tones is Fletcher's equal loudness contours [Fletcher[1]]. This work demonstrates that the human perception of loudness varies for tones at different frequencies. The concept was used to form the equal loudness contours. Zwicker's tone to noise ratio [Zwicker[2]] is considered one of the initial tone correction procedures. The work included critical band theory used by researchers and international standards that followed. Tones are rarely found in areas without considerable background noise or masking. Masking was found to be dependant on both the level of the tone over the background noise, and the level of the background noise itself [Stevens[3]]. This work was a starting point in the evaluation of tones that followed, including correction methods [Wells and Blazier[4]]. Pearsons [Pearsons et al[5]] completed a study on tones with variable background noise. The work applied two different background spectra that resulted in a negligible change in reported noisiness, with maximum noisiness reported when the tone to noise ratio reached 25 dB.

Kryter and Pearsons [Kryter and Pearsons[6]] developed a methodology based on the judgment of random train noise containing a pure tone, resulting in the Tone Corrected Perceived Noise Level. The Federal Aviation Regulation (FAR) Part 36 [FAR[7], 1969] describes a tonal correction based on subjective responses to aircraft. FAR 36, Section A36.4 outlines the process known as the Effective Perceived Noise Level (EPNL) which is a single number evaluator of the subjective effects of noise. The EPNL correction increases with increasing tone to noise ratio. Patsouras [Patsouras[8]] investigated the behavior of 14 subjects when exposed to synthesized simulations of high speed train interiors. With a focus on rail and motor noise, the results indicated that receptor annoyance scores increased with higher tone prominence. Early environmental work [Kryter[9], Scharf and Hellman[10]] found that common metrics such as dBA and $L_{dn}$ underestimated the perceived impact of tones. Experiments confirmed that a single tone contributes more to annoyance than an equivalent amount of energy spread over a wide range of frequencies, resulting in a 2 to 15 dB Tonal Penalty (TP). Scharf and Hellman found that tone correction was most suitable for constant noise, as found within most buildings, instead of the variable tones emitted from transportation sources. Landstrom [Landstrom et al[11]] studied the impact of three ventilation noise spectra. Subject concentration levels were found to be lower for the tone exposure as compared with the masked tone. The National Physical Laboratory [Porter[12]] studied the subjective response to traffic, compressor, and fan noise, including development of a TP for added annoyance. The study reaffirmed that the lower the background level, the more sever a TP. At 35 dBA, the study revealed a TP of more than 10 dB. As background levels increase to 60 dBA, the TP approaches zero. Of the common types of industrial sources, 35% were fans, with 80% of all sources having distinct characteristics (50% described as tonal).

Standards development has moved forward with the research on environmental noise and psychoacoustics. The British Standard for rating industrial emissions onto sensitive receptors [BS 4142[13]] provides one of the earliest prediction methodologies, including a TP. The standard addresses mechanical noise and the additional measurements for tone identification. A popular standard for the assessment of noise is ISO 1996 [ISO 1996-1[14]], that includes correction factors for increased annoyance. Although the methodology used to evaluate a TP differs from country to country, the principles are based on the provisions outlined in ISO 1996. Most countries have adopted a TP in the assessment of transportation and industrial noise between 2 to 6 dB. The ANSI S12.9 Part 3 [ANSI S12.9[15]] standard outlines the 1/3-octave band procedure for the description and measurement of environmental sounds. The ANSI S12.10 standard [ANSI S12.10[16]] provides a detailed assessment of tones through the Prominence Ratio (PR), based on the tonal sound level compared with the average level of the two adjacent bands. The ISO 9296 [ISO 9296[17]] explains there is no current international consensus on objective methods for rating the character of tones. The Air-Conditioning and Refrigeration Institute (ARI) standards have adopted tone adjusted ratings, such as ARI 350 [AIR 350[18]] for indoor equipment. This is supported in ARI 1140 [ARI 1140[19]] with a Sound Quality Indicator (SQI), where "levels are weighted to adjust for psychoacoustic sensitivity to frequency distribution and any discrete tones…converted to a single number SQI" (ARI 1140, page 2). The adjustment is required for any band that exceeds its two adjacent bands by more than 1.5 dB. The corrected levels are converted into indices weighed by frequency and level, "…by which complex sounds of various levels and spectra may be ordered and compared on a scale of subjective magnitude...provide a means to evaluate the quality of the product sound." (ARI 1140-2006, page 3).

An indoor setting is dependant on many non-acoustical factors, including room aesthetics and occupant occupation. A recent study by Health Canada [Health Canada[20]] found that while less than 10% of the people surveyed were either very bothered or extremely bothered by noise exposure, there appeared to be significant variance amongst populations (5% very bothered in urban areas versus 1% very bothered in rural areas) and amongst geographical regions (e.g. 5% very bothered in Ontario versus 2.4% very bothered in Alberta). One may conclude that if a tone study were conducted in an industrial, rural town, they may receive significantly different results if the same study was conducted in a non-industrial, urban area.

## 3. TONALITY IN BUILDINGS

Present room criteria may be used as the basis of an acoustical design, evaluating the background noise against the preference of the occupants. The criteria do not sufficiently characterize the effects of tones. Using the current guidelines as a starting point, a refined approach may be available for the initial building design stage and an in-field evaluation, such as commissioning and troubleshooting. Adverse effects are present if the occupant has the ability to distinguish the tone over the background. Low noise work spaces often entail high concentration levels. Critical design criteria call for more stringent evaluations of audibility, often applied through the critical band masking concept [Zwicker and Fastl[21]] where only noise within a critical band can determine tone audibility.

## 4. DISCUSSION

Acoustic comfort has emerged as a key building design issue. Tonality may be a significant occupant issue as a result of annoyance. Although the literature lacks clear tone criteria for a building, there appears to be agreement on the identification of tones, primarily mechanical systems. It is evident that there are practical solutions available that may protect building occupants from tones. In lieu of reliable indoor tone criteria, designers should consider:

1. TP for all applicable building equipment and services under existing noise criteria (dBA, NC, RC)

Or;

2. TP on the noise criteria, analogous to those applied in environmental ordinances (margin of safety).

Obtaining tone-penalized ratings is a feasible option and a first step towards protecting building occupants from annoyance, reduced productivity, and costly repairs.

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