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Low frequency noise and disturbance assessment methods: A brief literature overview and a new proposal

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Several studies have presented the effects of environmental noise on communities, focusing attention on sleep time events. The noise introduced into a dwelling 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 sleep time. The aim of this contribution is to analyse the low frequency disturbance phenomenon into technical and scientific literature and to investigate if any possible objective method is available in order to assess noise disturbance inside dwellings.

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1. INTRODUCTION

Low frequency noise (LFN) is mostly related to complaints, often associated to intense, pulsing and annoying effects. At the same time the sufferers perceive these sounds in a different way from instruments or other people and these aspects could cause misunderstandings. Existing and consolidated assessment methods are widely based on the A-weighted sound pressure level measurements. But this parameter leads to an underestimation of mid and low frequencies [1]-[4].

The causes of such suffering are not completely clear and many case studies have not been explained yet. Low frequencies wavelength and very long propagating paths determine very difficult measurement procedure since many uncertainties occur. In particular Benton [4] pointed out that the quantification of each of these aspects is often complicated by the combination of significant "individual differences".

Furthermore, as clearly stated by Moorhouse et al. [5] the sensed LFN increase rapidly with increasing acoustic energy and so low frequency levels just above the hearing threshold can be perceived as loud, even uncomfortably loud.

According to Di et al. [6] the A-weighted sound pressure level could not provide a good identification of disturbance in subjective response. Shepad et al. [7] described how LFN effects are less recognized when compared to the noise at other frequencies; they also highlighted the different annoyance range caused by exposure to low, medium or high frequency noise compared to the same A-weighted sound pressure level. Jabben and Verheijen [8] discussed the possibility that the complaints are caused by a lower insulation provided by walls and façades.

As described, the LFN causes, propagations and effects are not clear and need to be deeply investigated yet. Though, a brief overview is thereby provided.

2. FREQUENCY RANGE AND THRESHOLDS

A. LOW FREQUENCY VS. INFRASOUND

There is not a clear and certain international identification of the LFN range. Some authors and standards use the 10 Hz to 100 Hz range [9] - [10], while others refer of a wider one [11]-[13] since sources provide different emission trends [14]. In these second range the infrasound are also included; nevertheless clear international definition of infrasound is not available too, since every paper describes and states its own classification. However the IEC standard [15] defines LFN as the frequency below the low limit audible sound (about 16 Hz), whether Watanable and Moller [16] have reported that a sound down to 1.5 Hz is audible in an acoustic chamber if its level is higher enough.

B. HEARING THRESHOLDS

Benton [4] reported a comparison between the Watanable and Moller threshold and the ISO 226: 2003 [17] one: as shown in Figure 1, the two trends are very similar.

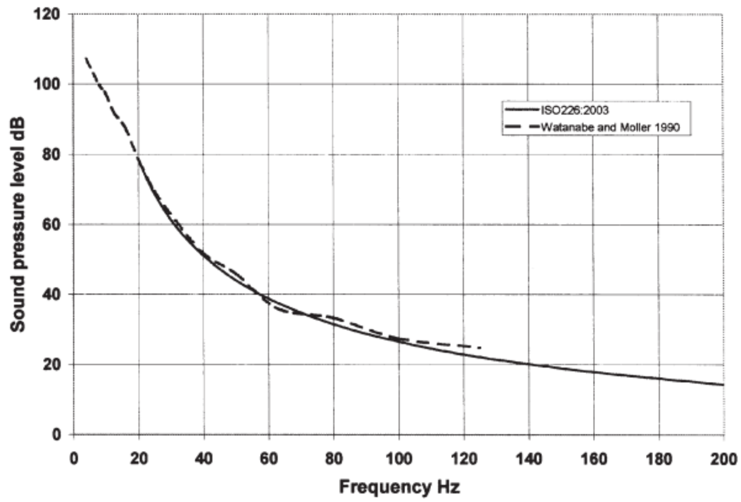

Figure 1 – low frequency thresholds [4]

Though, as Leventhall [18] highlighted, there is no evidence that infrasound are inaudible and so there is no clear border between "infra" and "normal" sounds.

Leventhall et. al [19] have explained the effects of aging on hearing sensitivity. The statistics of hearing loss related to age are contained in ISO 7029 [20] which considers the 125 Hz band as the minimum range. The standards highlight how the hearing loss reduces as the frequency drops and the results summarized in table I [19] show how at low frequency the difference between young and elderly people is very restricted.

The difference in hearing sensitivity between elderly and young people is verified just at medium and high frequencies but not in low frequency range. This could be explained by the fact that low frequencies are heard both by using chest and ears [1].

Table 1 – low frequency hearing threshold for old and young people [19]

	Otologically unselected population 50 - 60 years old		Otologically selected young adults (ISO 226:1987)	
Frequency Hz	50% Level dB	10% Level dB	50% Level dB	10% Level dB
10	103	92	96	89
12.5	99	88	92	85
16	95	84	88	81
20	85	74	78	71
25	75	64	66	59
31.5	66	55	59	52
40	58	46	51	43
50	51	39	44	36
63	45	33	38	30
80	39	27	32	24
100	34	22	27	19
125	29	18	22	15
160	25	14	18	11
200	22	10	15	7

C. HEARING VS. ANNOYANCE

In previous paragraphs a very brief literature overview have been presented. A very important question now has to be asked: is an audible noise disturbing? It is enough to define as annoyance a perceived sound?

Lenventhall [18] explained that the emotions greatly influence the final response. The sensitization to noise may enhance the perceived sound causing different effects on people. As Schnupp and Kacelnick reported [21], plasticity is included in brain skills. So a huge exposure to particular frequency stimuli may lead to improved discrimination ability and an expansion of the cortical area response. As a consequence, if people are exposed to low frequency noise, they may develop an aversion to it, causing an enhanced hearing sensitivity.

D. THE USE OF dB(A)

The single value of A-weighted sound pressure level is sometimes used as annoyance threshold: the WHO guidelines [21] propose a health-based limit for night time exposure inside dwellings; the Italian law [23] provides L_{Aeq} limits in order to asses annoyance during day time and night time periods inside and outside buildings, analyzing the tonal components at low frequency range (below 100 Hz).

3. FREQUENCY RANGE AND THRESHOLDS

The assessment criteria are generally based on the overcoming of a specific threshold.

For traffic noise, Miedema and Oudshoorn [25] connected annoyance with noise, focusing on transportation sources using DNL and DEN values.

For noise produced by fixed sources Mirowska [11] reported a robust and detailed method, used as legal requirement in Poland. In this criterion, the 1/3 octave band comparison between the background noise and the disturbing noise is requested. Then, the latter one is compared to a given threshold which has not to be exceeded.

Jakobsen [26] focused on the 10 Hz – 160 Hz bandwidth and used a logarithmic summation of these 1/3 octave bands. The measurements must be performed in three different positions and the final value is obtained by levels averaging; this method includes assessment of vibrations disturbance.

Roberts [27] has used the same Jakobsen's parameters [26] but considering different thresholds for disco music sources.

Caniato et al. [13] proposed a harmonized method based on the exceeding of a disturbance threshold using very strickt measurement guidelines.

Standard DIN 45680:1997 [28] and the following draft [29] describe a first check of the measured noise using a comparison between L_{Ceq} and L_{Aeq} parameters. Then a weighting method is applied and the use of a not exceeding given threshold is prescribed in order to assess the disturbance.

4. DISCUSSION AND NEW PROPOSAL

Even if several objective methods exist and in some case their application is required by the law, the measurements are limited in results as they only deal with one part of the disturbing phenomenon.

On the other hand it is necessary to have a comparable, reproducible and international method to assess whether the disturbance is present or not. Without this criterion it would not be possible to understand, to assess and consequently to design any of the several low frequency sources needed for our lives.

So, unlike some authors state [18]-[19], the need to provide an objective and repeatable result, for example in lawsuit or complaints, using robust measurement method is a matter of fact. Low frequency disturbance is an issue that should be managed both in environmental and in building acoustics [30] - [32], since neighborhood noise in dwellings is the first cause of argue.

During last years, many scientists proposed different solution and thresholds (see Figure 2) and recently and average of the average (comparable methods) was proposed [13]. This latter method aims at the average of individual behavior and sensitivity, basing on the fact that this is the only way to include as many people as possible.

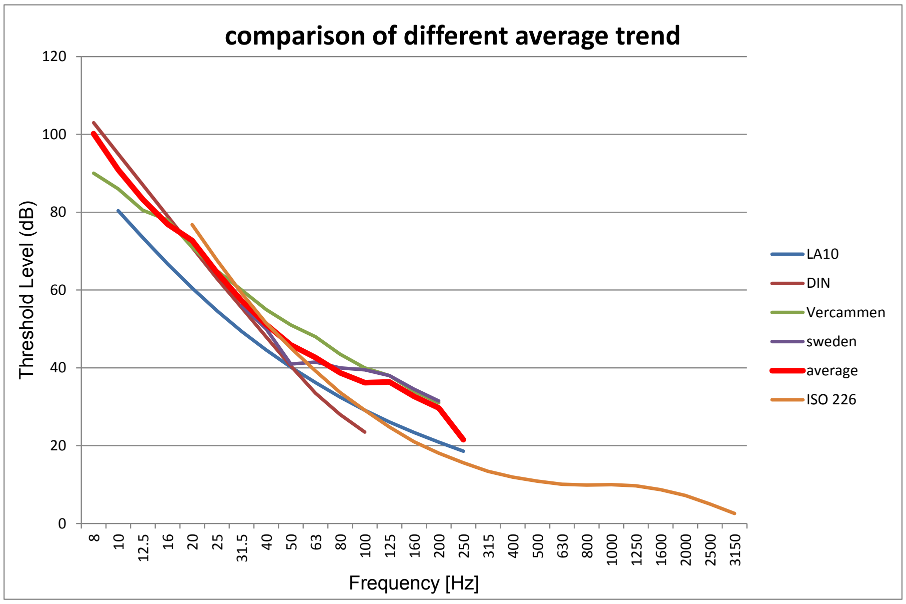

Figure 2 – frequency thresholds [13]

Strickt criteria and guidelines are needed in order to perform reproducible and robust measurements; therefore a new proposal was developed [13]:

1) Noise should be measured both inside the dwelling where the disturbance is higher and close to the source. If the source signal is stable enough, then this measurement can be carried out separately. If the 1/3 octave bands trend of the former is comparable with the latter (also a composition noise due to many sources), then this method can be used, according to [33]. The source measurements have to be carried out at a distance of 1 meter from the highest emitting point. If the noise source is composite (industrial plant) then the microphone should be placed in a position equally distant from different sources in a normal direction starting from the focal point of the overall surface. If this is not possible (close walls, irregular shape) the instrument needs to be placed closer to the surface, remaining in a perpendicular direction starting from the focal point.

2) The residual noise (source(s) off) should be measured in the same period of the day (or night) and week before or after the noise source is used.

3) The residual noise should be compared with the disturbing noise. If the difference (in 1/3 octave band analysis) is higher than 6 dB according to [6], the disturbance can be evaluated using following steps.

4) The measured disturbing noise within dwellings should be compared with the average threshold. If the former exceeds, the following two different scenarios must be considered:

a. If it is night time (from 22 to 7 h), if the receivers are children up to the age of 3 or people with serious illnesses (all day long), if the receivers are in hospitals or schools or buildings where silence is needed (all day long), then the excess of the threshold confirms the existence of the disturbance. Night time period (22-7) represents the typical and average sleep time of children and workers.

b.If none of the above conditions occur, the excess has to be equal to or higher than 3 dB according to [23] in any 1/3 octave band.

Measurement guidelines:

1) A minimum of three different 15-minute measurements has to be averaged. If the noise is shorter, then multiple receivers are needed (3 minimum) with at least 1 minute measurement time each. The microphone(s) needs to be 50 cm away from each other. If the noise source(s) is not constant (e.g. concert, short and repeated HVAC cycle etc.) and the related residual noise is shorter than 2 minutes, then the measures have to be post-processed in order to compute only the disturbing noise and to exclude the residual noise. The minimum sampling step should be set to 1 second. The described time ranges are based on the authors' measurement experience related to the development of this study and concern the minimum time lapse within whom the sound event could be considered robust and reliable.

2) At the same time an instrument must be placed near the source(s) in order to acquire the frequency trend. If the signal is stable enough, then this measurement can be carried out separately (before or after those in dwellings).

3) No other person except the technician(s) must be present during the measurements. All the external acoustic events are to be taken into account and post-processed to avoid any outer interference.

4) All doors and windows must be closed.

5) The measurements must be carried out in closed rooms such as dining room, living room, bedroom, etc. No corridors, storerooms, bathrooms smaller than 8 square meters (minimum area for repeatable measurements, taking into account furniture, room shape etc.) should be considered.

Providing results:

1) Report measurement methodology

2) Identify irrelevant acoustic events during measurement operation and do not consider them while assessing the disturbance

3) Report name, type and certification of the instrumentation

4) Describe the source type and report the frequency and trend.

5) Attach pictures of the measurements and sources

6) Report the 1/3 octave band assessment trend indicating if and where the presence of a noise disturbance is confirmed

7) Propose possible solutions

5. FINAL REMARKS

Low frequency noise is considered as one of the first issue to be solved worldwide. As a consequence, many researchers have tried to define objective methods to determine whether a disturbance is assessed or not.

A brief literature overview was presented concerning the low frequency noise phenomenon, the human hearing and the method to assess the disturbance.

The aim of this paper is to start a discussion and inform stakeholders in the drafting of new standards or legislation, or in the integration of existing legal requirements. A new objective method is proposed, built on robust and scientific criteria that should replace the current widely used procedures and their subjective interpretation.

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