



Effect of infrasound and low-frequency noise with regard to loudness estimation

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Due to trend towards renewable energy technologies more and more e.g. biogas plant, wind energy plants are established. Therefor in Germany, the sensitivity of the concerned population in particular regarding to low frequency noise and infrasound has increased intensively. In a feasibility study initiated by the German federal environmental agency (“Umweltbundesamt”) the main sources were identified, the state of the art regarding the noise effects was determined and the concern of the German population estimated. Thereby it figured out that concerned persons do not feel sufficiently supported by the current approach according to the German standards of evaluation. By means of typical examples of application the analysis of low frequency sounds by common spectral frequency weighting methods is compared to the loudness analysis of Zwicker. A possible approach for the evaluation of low frequency noise is derived.

1 INTRODUCTION

In Germany, citizens have increasingly complained about negative effects caused by low frequency noise and infrasound or the so-called hum phenomena (“Brumnton Effekt”) in recent years. This includes cases in which these effects were caused by both identifiable technical installations and unknown sources of noise. Especially in the case of immissions from technical installations, effects of the low-frequency noise and the audible infrasound can occur for itself and in superposition of both effects in the audible range. Due to the long wavelength of infrasound phenomena of multiple meters and the extremely small reduction of infrasound over the distance, there are also many cases of non-identifiable infrasound immissions.

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The assessment and evaluation of low frequency noise is currently performed in the ISO 1996-1¹. There, the main reasons for the different perception of low frequency sounds versus mid and high frequency sounds and the different approach of various countries regarding low frequency analysis (e.g. G-weighting, octave-band or one-third octave band analysis) is summarized.

In Germany, low frequency noise is assessed according to the Technical Instructions on Noise Abatement (“TA Lärm”) in its 1998 version² together with DIN 45680 “Measurement and Assessment of Low Frequency Noise Immissions in the Neighbourhood” of 1997³. These regulations just consider noise components that exceed a defined (medium) auditory threshold in third octave bands.

However, the public increasingly refers to the insufficient level of protection against low frequency immissions and demands stronger limitations. The potentially close causal relationship between acoustic perceptibility (auditory threshold) and the experiencing of noise pollution must be reconsidered with regard to persons who have a lowered auditory threshold or became more sensitive by long term exposure. Especially in cases of low frequencies, the dynamics between perceptible noises and the pain threshold are lower in comparison to the medium frequencies of the audible range. This is why there is a suspicion that persons with a lowered auditory threshold could already experience annoyances even though the hearing curve for medium frequencies has not yet been exceeded. It is still largely unclear at present which extra-auditory mechanisms of action could lead to additional annoyance.

Figure 1 shows the hearing area and the curves of equal loudness with respect to the areas of infrasound and low frequency noise. In the following infrasound is defined as sound in the frequency range between 0,1 Hz and 20 Hz. Usually the 16Hz-octave band is still excluded from the audible range and is therefore the limit between infrasound and the hearing area. For this reason, the upper 1/3-octave band of the 16Hz- octave band with the center frequency of 20Hz is mostly still attributed to the infra sound range even if this 1/3-octave band is per definition not completely within the range of infrasound.

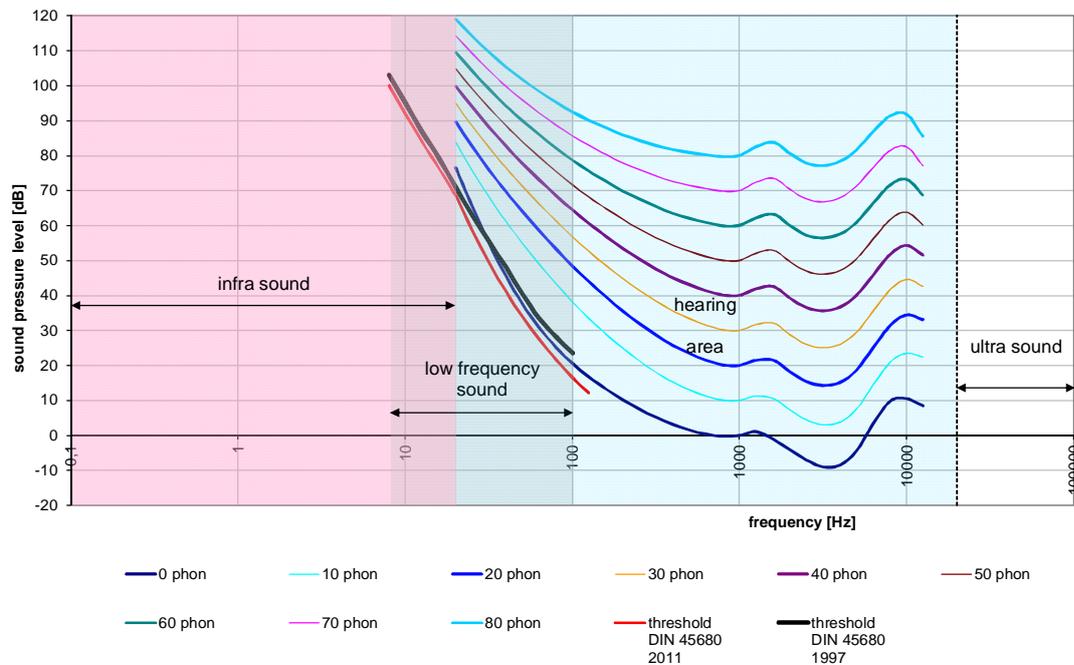


Fig. 1 – Hearing area and curves of equal loudness according to DIN ISO 226⁴ with respect to infrasound and low frequency noise ranges.

2 FEASIBILITY STUDY

A feasibility study⁵ was initiated by the German federal environmental agency to identify the main infrasound sources and the potential concerns in Germany due to infrasound.

2.1 Concerns of population

In order to determine a concrete noise pollution situation and the frequency of complaints about infrasound and low frequency noise immissions, a survey of public authorities was conducted on this topic. The polling of authorities occurred in three stages:

1. The environmental agencies of the German federal states were contacted to evaluate the complaint situation and how much the population was affected concerning infrasound. Subsequently, selected federal states environmental agencies were contacted via telephone to acquire additional information.
2. The subordinated immission control authorities were contacted by mail. Initial telephone contacts with specific subordinated immission control authorities revealed that complaint registries are handled on an individual basis. A questionnaire was developed based on these insights.
3. The questionnaire was distributed at the beginning of 2013. About 400 lower-level immission control authorities were contacted by mail at this time. The feedback and evaluation of the questionnaires was completed in June 2013. The response rate was 34.2%.

The analyses of the feedback showed the existing lack of a uniform complaint registry. Furthermore, there are no standardized methods for a comparative and systematically ordered database. This problem is amplified by the fact that there are currently no generally accepted measurement and evaluation regulations regarding especially the infrasound range (from 0.1 to 20 Hz). The complaints often completely lack objective proof about the magnitude of the noise exposure. Many representations of interests with Internet pages and public relations work result in a confusing situation of affected people in the broadcasts. This is dominated by reports of individually affected persons, who most often only state their presumptions about the cause of the noise exposure in a strongly abbreviated form and describe their symptoms in a qualitative way without indicating a reference to acoustic values or other objective data. The development and maintenance of a uniform centralized complaint registry for infrasound and low frequency noise would be meaningful in the future. The archiving of existing measurements of the linear one-third octave levels of low frequency sound pressure level in the frequency range from 8 to 100 Hz could be used for the initial comparative analysis of key acoustic parameters. Official sound level measurements and expert opinions, as well as event-related monitoring by the affected persons themselves, can be used for this purpose. However, sound level measurement data and average times, the class characteristics (according to the proposed classification) and additional key values that could be the cause of the increased noise pollution (e.g. vibrations, secondary effects, meteorological effects, etc.) should also be collected within the scope of future sound level measurements. The information could be used as the basis of a possible multi-dimensional threshold determination for the low noise and the infrasound range.

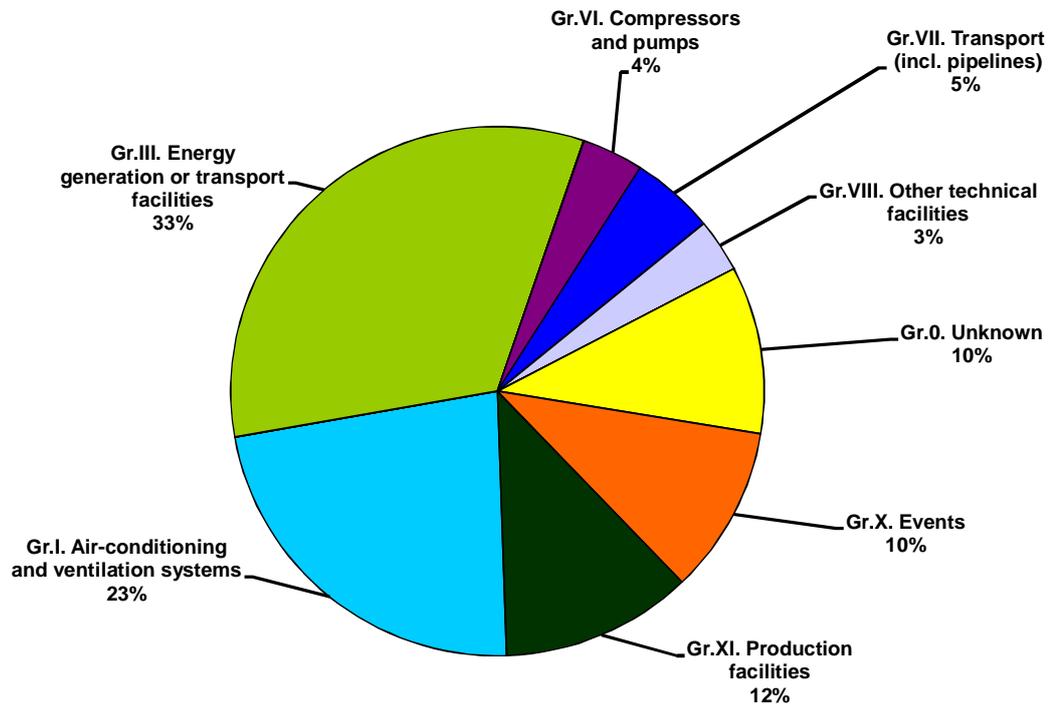


Fig. 2 – Distribution in percentage of complaints regarding infrasound and low frequency noises in Germany.

In summary, the following findings resulted from the conducted analysis of the affected population:

- Regional focal points could not be statistically determined with sufficient certainty. In particular, the quantity and representative value of the submitted complaints was too low for this purpose. The general tendency showed a higher number of complaints in Southern Germany.
- Most of them indicated power plants or energy transport (33.0% of the cases), as well as air-conditioning and ventilation systems (22.8% of the cases), in reference to their complaints about infrasound and low frequency noise.
- Heat pumps were mentioned as the most frequent source for complaints with an overall share of 9.3%. Among facilities for energy generation and transport, biogas plants (8.4%), thermal power stations (6.5%) and wind energy plants (3.3%) most frequently lead to conflicts.
- For the purpose of systematic study of noise impact, installations with a high number of affected persons should be selected such as thermal power stations, wind energy plants and presses and punching machines in production plants. Therefore, primarily the research in heat pumps, cooling and air-conditioning systems, heating and ventilation system in a residential environment would be suitable for preventing practical conflicts and improving the quality of living conditions in relation to infrasound and low frequency noise.

It must be noted that the survey of authorities reflects just a small portion of the actually existing conflict situations regarding the effects of infrasound and low frequency noise. It must be

presumed that individual tolerance levels of affected citizens could possibly lead to just a small fraction of conflicts being reported to the authorities. In order to achieve a more accurate picture of the situation, the frequency of objections in planning procedures and legal disputes should be analyzed.

2.2 State of the art

A literature research realized in the context of the feasibility study goes back to the year of 1950. The earlier publications are concentrated on the direct physical effect of low frequency noise and infrasound, mostly with sound pressure levels above 100dB. Studies with lower levels however were rare and concentrated on the question of threshold in quiet. A collection can be found for example in Schust⁶ and Fidell et al.⁷.

Already in the investigations of Broner and Leventhall⁸ and Andersen and Møller⁹ in the 1980s it has been stated that low frequency noise can be extremely annoying. Since the end of the 1990s, an increasingly number of publications is therefore concerning with the annoyance of low frequency noise. The growing interest on this topic can be explained by the growing number of potential low frequency sound sources. This seems to have increased the sensitivity towards their noise.

Figure 3 shows the distribution of the collected publications by the year of publication in between 1950 and 2012.

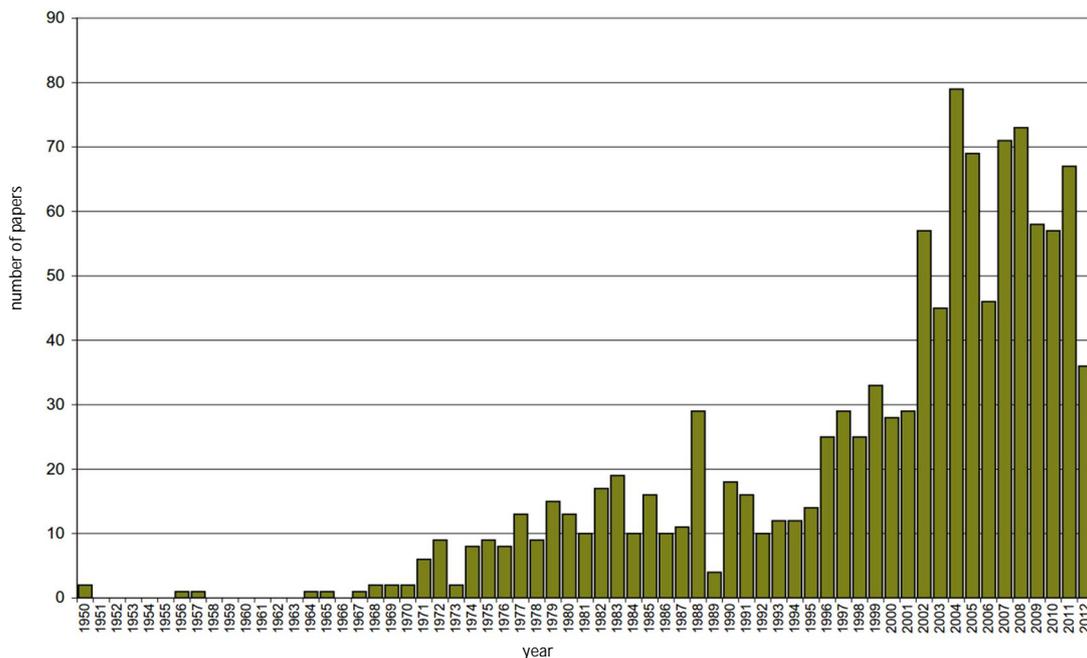


Fig. 3 – Number of papers since 1950 concerning with low frequencies collected in a database.

The database containing approx. 1200 articles is available as the result of the literature review. The articles are filed by keywords and relevance criteria. It is not possible to provide public access to full texts in the database due to copyright reasons. However, one version that at least contains source references and abstracts (if any) is available on a publicly accessible server. More details on the database can be accessed on the website of the infrasound feasibility study at <http://www.infraschallstudie.de>

2.3 Legislation

A description of various European legislation regarding noise protection of low frequency sounds and infrasound can be found e.g. at Moorhouse et al.¹⁰. However, it must be underlined that the reference values are varying. Furthermore, the lower and upper cutoff frequency for the respectively reference values are different.

Figure 4 gives an overview of European reference values for low frequency noise and characteristic percentile levels of the hearing thresholds of otologically normal persons between 18 years and 25 years under free-field listening conditions according to ISO 28961¹¹.

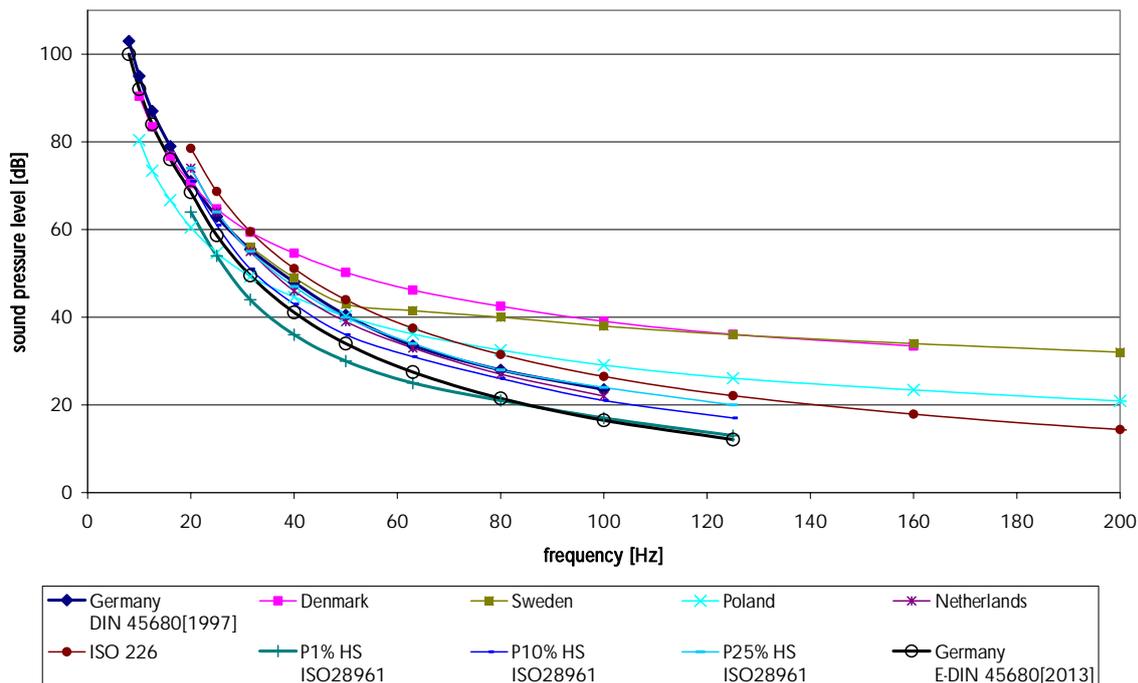


Fig. 4 – Reference values in different countries and percentile levels of the hearing thresholds for low frequency levels

3 EXAMPLES OF APPLICATION

In the following two examples of application are analyzed. In figure 5 two seconds of the measured time signal of a biogas plant (left hand side) and a heat energy plant (right hand side) are displayed. Below the today's usual analysis of linear and A-weighted 1/3 octave levels are figured. Furthermore, the specific loudness of the signals is calculated. Due to DIN 45631¹², the 1/3 octave levels of frequencies below 250Hz have to be summed up in the critical band levels LG1 to LG3:

„Due to the fact, that the critical bands in the low frequency range are wider than one 1/3 octave band, it is necessary that the measured 1/3 octave bands are summed up in the critical bands LG1, LG2 and LG3:

LG1: all 1/3 octave bands with the center frequencies from 25Hz to 80Hz

LG2: all 1/3 octave bands with the center frequencies from 100 to 160Hz

LG3: all 1/3 octave bands with the center frequencies from 200Hz to 250Hz“

Thus, the spectral enhancements in low frequency ranges are assessed by the loudness respectively to the critical band existing in our hearing system.

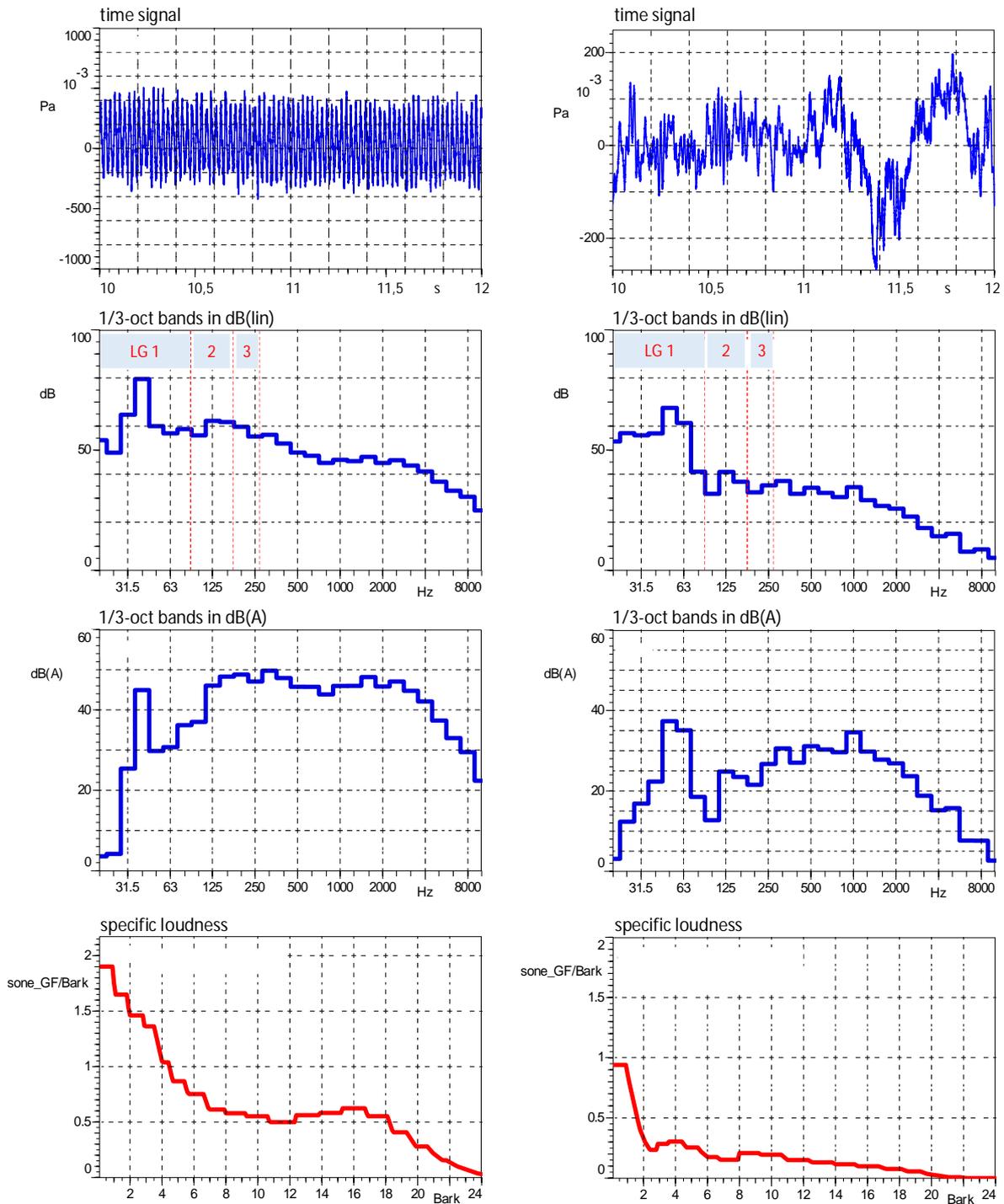


Fig. 5– Time signal and linear resp. A-weighted 1/3 octave bands versus specific loudness for the examples of a bio gas plant (left hand side) and a heat energy plant (right hand side).

4 DISCUSSION AND CONCLUSIONS

As a result of the changing energy policy in Germany more and more renewable energy plants as for example bio gas or wind energy plants are installed. The sound emission of these energy-generating systems show significant contents in low frequencies and infrasound next to residential areas. Therefore, more and more concerned people complain in particular about low-frequency noise. The national and international standards are not sufficient to react appropriately to this annoyance.

To evaluate the annoyance of low-frequency noise the specific loudness can be used. There, low frequencies are considered respectively to the critical bands in our hearing system. However, the current standard for loudness calculation considers only frequencies down to the 1/3-octave band with a center frequency of 25Hz. To assess also the annoyance of sounds with frequencies below 25Hz, further research has to be conducted regarding thresholds of low frequencies. In literature there are very differing data regarding thresholds of low frequencies available. This might be caused on the one hand by comparable play back units for low frequencies, but also on the apparent difference in threshold of the individuals. A possible approach could be the definition of a very low percentile value of threshold for the “standard threshold”¹³.

Another important factor for the annoyance of low frequencies is the existence of modulated signal components, as for example measurable by the fluctuation strength. Due to the increased installation of energy-generating systems with low frequency contents in total a modulated noise with a high annoyance factor can occur. A kind of “modulation malus” in dB could be a possible approach to differentiate between modulated and not modulated signals.

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