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Low-Frequency Noise Complaints in Styria: A Project-Based Assessment of Selected Cases Using DIN 45680 and Statistical Hearing-Threshold Criteria

Florian Lackner[1*]

[1]*Noise and Radiation Protection, Office of the Styrian Government, Landhausgasse 7, 8010 Graz, Austria*

Abstract

Since 2021, the Styrian provincial authority has received an increasing number of complaints concerning low-frequency noise. By March 2024, 46 complaints had been registered, of which eight cases were investigated in detail through night-time third-octave-band measurements following DIN 45680. A-weighted sound pressure levels inside affected dwellings were typically below 15 dB, corresponding to very quiet indoor conditions. One of the eight cases, an air-source heat pump in a pure residential zone, exceeded the DIN 45680 reference values for significant annoyance in terms of the maximum one-third-octave level, while two further complaints were attributable to noise in the audible range rather than to actual low-frequency components. To account for individual differences in low-frequency hearing sensitivity, the assessment was complemented by comparison with statistical hearing-threshold curves derived using ISO 389-7 and ISO 28961 (1st and 10th percentile thresholds) and by evaluation of the G-weighted infrasound level. In most cases, the measured spectra lie well below the extended assessment criteria, indicating that low-frequency noise is unlikely to be the cause of the reported perception. These observations suggest that the unusually quiet conditions in the affected dwellings themselves contribute to the perception.

Keywords: *low-frequency noise, environmental noise assessment, DIN 45680*

1. Introduction

Low-frequency noise is an established and distinct problem in environmental noise assessment [1], [2] which remains subject of active research [3] and receives ongoing attention from environmental authorities [4]. Affected residents typically describe the noise as a continuous low-pitched humming sound that is most noticeable indoors and during quiet night-time hours. Note that the reported sensation is referred to as a low-frequency sound percept [3], a designation that does not presume an external physical source. Detailed studies of such complaints [5] and a classification of environmental hums and low-frequency tinnitus [6] have been reported previously.

In the Austrian federal state of Styria, low-frequency noise (LFN) complaints have received increasing attention from the provincial authority since 2021, and subsequent media coverage was followed by a rise in the number of registered cases. By March 2024, 46 complaints had been documented at the Office of the Styrian Government, eight of which were investigated in detail in a dedicated project comprising a series of night-time measurements [7]. Note that this selection follows from the legal framework, since an investigation requires a formal assignment by an authority, for which the complaint has to be related to an authorized installation [7]. The present paper summarizes the findings from these case studies, evaluated within the framework of the currently applied standard DIN 45680 [8], [9], and extends the typical assessment practice by taking individual differences in hearing sensitivity into account and by reporting G-weighted sound pressure levels.

2. Background and assessment framework

2.1 Low-frequency sound and infrasound

According to DIN 45680 [8] low-frequency sound is defined as sound in the one-third-octave bands from 8 Hz to 100 Hz (extended range), with an upper band edge at 112 Hz. With decreasing frequency, the ability to perceive tone and pitch decreases, and below approximately 16 to 20 Hz, in the infrasound regime, sound is typically perceived as a discontinuous

Corresponding author: f.lackner@stmk.gv.at.

pulsation accompanied by a sensation of vibration [10], [11]. Owing to their large wavelengths (3.4 m at 100 Hz, 34 m at 10 Hz), low-frequency components propagate with negligible atmospheric attenuation and are only weakly shielded by terrain features or building envelopes, the latter acting as acoustic low-pass filters. Inside buildings a further phenomenon favors the formation of low-frequency sound fields [12]. Depending on the room geometry, standing waves can develop, the lowest axial mode amounting to about 57 Hz for a room of $3 \times 3 \times 3$ m³ and to about 34 Hz for a room of $5 \times 5 \times 3$ m³. Room modes of typical living spaces therefore fall into the same frequency region in which the closest approach to the reference curves is observed in the cases reported below [7].

2.2 DIN 45680 and international assessment criteria

DIN 45680 (1997) [8], [9] is the standard applied in Austrian administrative practice for the evaluation of low-frequency noise in protected indoor spaces. The standard requires the criterion $L_{\mathrm{Ceq}} - L_{\mathrm{Aeq}} > 20$ dB to be fulfilled for low-frequency content to be considered relevant. Reference values for significant annoyance are provided in the supporting part of DIN 45680 [9] for two cases: broadband spectra and spectra with prominent individual tones, the latter being the more stringent criterion. Separate reference values are given for the one-third-octave assessment level $L_{\mathrm{Terz,r}}$ and for the maximum level $L_{\mathrm{Terz,Fmax}}$. For the night-time period and frequencies below 63 Hz, the night-time reference curve coincides with the listed DIN 45680 hearing threshold L_{HS} so that exceeding the hearing threshold alone is sufficient to assume significant annoyance according to the standard.

A comparison with assessment criteria employed in other countries (Denmark, Finland, Japan, the Netherlands, Poland, Sweden) [12], [13] shows that the protection level provided by DIN 45680 is among the stricter ones, particularly around 60 Hz. For infrasound, only a few countries specify an explicit limit. The Danish [14] criterion of $L_{\mathrm{Geq}} = 85$ dB (G-weighted sound pressure level following ISO 7196 [15]) is used as a complementary descriptor in the present work. Note that this is in agreement with the technical specification DIN/TS 45610-1 [16] and the accompanying technical report DIN/TR 45610-2 [17], both published recently in 2026. It should be noted, however, that these documents do not replace DIN 45680 [8], which remains valid and therefore continues to provide the basis of the present assessment.

2.3 Perception threshold and percentile hearing thresholds

Individual hearing thresholds in the low-frequency range exhibit a standard deviation of approximately 5 dB. Consequently, the hearing thresholds of about 95 % of the population fall within an interval of about 20 dB. The reference threshold of hearing is given in ISO 389-7 [18], and ISO 28961 [19], [20] provides the statistical distribution of hearing thresholds of otologically normal persons aged 18 to 25 years, from which percentile thresholds can be derived. The first percentile [21] denotes the level at which only the most sensitive 1 % of the population are still able to perceive a tone, and this curve is referred to in the following as the perception threshold. A comparison carried out here shows that the threshold used in DIN 45680 corresponds to the 25$^{\mathrm{th}}$ percentile, thus a quarter of the population hears better than the standard assumes.

In analogy to the 10 % criterion applied by the WHO to the proportion of highly annoyed persons [22], the 10th percentile threshold derived from ISO 28961 is included in the following as an additional reference curve, together with the DIN 45680 reference curves and the 1st percentile perception threshold. Note that ISO 28961 provides no values below 20 Hz, so that the perception threshold has to be extrapolated in this range [21].

2.4 Reported perceptions and typical indoor conditions

A first impression of each case is obtained during the initial contact, in the course of which a standardized survey sheet is completed [7]. The sound perception is described by the complainants as clearly noticeable and is most often characterized as a humming or booming sound. It is usually described as present at all times, though its intensity is reported to vary over days and weeks in every case. In addition, it is reported to be most noticeable at night, when the background noise is lowest. The descriptions range from disturbing and annoying to unbearable, and in extreme cases a health hazard is associated with the perception in the residents' self-assessment, above all through sleep disturbance caused by its constant presence.

The indoor conditions encountered in the affected dwellings can be described throughout as very quiet, with A-weighted sound pressure levels below 15 dB and in part even below 10 dB. Note that such levels are reached only after secondary indoor sources have been switched off. In all but one case the low-frequency noise could not be perceived by the measurement technicians at all, and in that single case its perception required deliberate concentration and was possible only after the resting period described in section 3. Once the percept has been identified at the position where it is strongest, it is recognized more easily elsewhere, and a negative consequence of this conditioning for the affected residents may be that the perception becomes easier over time [7].

3. Measurement procedure

The measurements reported in the following were performed at night, typically starting between 22:00 and 23:00, since the strongest perception was consistently reported during these hours. After arrival on site, a resting period of at least 30 min was observed to allow the hearing of the measurement technicians to recover. A Norsonic Nor140 sound-level meter equipped with a low-noise microphone (GRAS 40AH in combination with a GRAS 40HL-N), calibrated before and after the measurement, was used to resolve the very low sound pressure levels encountered.

Prior to each measurement, secondary indoor sources that could mask the low-frequency content of interest were identified and switched off in cooperation with the residents, typical examples being refrigerators, pumps, plug-in power supplies, and even ticking clocks. At the very low levels encountered, typically $L_{\mathrm{Aeq}} \approx 10$ to 15 dB (comparable to human breathing at the ear), the persons present were instructed to remain still, and doors were kept closed to avoid air-mass displacement artifacts in the low-frequency range. Measurement points were placed near walls (respecting the minimum distance of 0.5 m according to DIN 45680) at locations where complainants reported the strongest perception. The total measurement duration was typically on the order of several minutes, within the core night period during which environmental interference is minimal.

For cases in which the low-frequency noise was not present during the initial measurement night (Case 2), long-term measurements were set up and analyzed. The employed device includes a trigger button that allows residents to mark intervals of strong perceived annoyance, enabling targeted analysis of the corresponding data segments.

4. Results

Four cases are described individually in the following, the remaining four are summarized together. Table 1 provides an overview of selected parameters for all eight investigated cases, the corresponding spectra are shown in Figure 1.

4.1 Case 1

A resident in Upper Styria reported a continuous low-frequency noise associated with a nearby industrial plant. Measurements at the suspected source (an exhaust stack at 20 m distance) yielded $L_{\mathrm{Aeq}} = 63$ dB and $L_{\mathrm{Ceq}} = 77$ dB. The difference of $L_{\mathrm{Ceq}} - L_{\mathrm{Aeq}} = 14$ dB does not meet the DIN 45680 criterion of 20 dB for low-frequency content at the emission point, but with increasing distance air absorption attenuates higher frequencies more strongly, and building envelopes act as low-pass filters, so that the source may still contribute to low-frequency immissions at the affected dwelling 350 m away. However, inside the dwelling only about $L_{\mathrm{Aeq}} = 12$ dB was measured in the assessed room, with levels below $L_{\mathrm{Aeq}} = 15$ dB in the remaining rooms and all one-third-octave assessment levels $L_{\mathrm{Terz,r}}$ were well below the DIN 45680 reference curve. A comparison between operation with the suspected source on and off showed no significant difference, excluding the stack as the dominant cause.

Close inspection of the recorded one-third-octave levels $L_{\mathrm{Terz,r}}$ in Figure 1 reveals that they remain below the 1st percentile perception threshold at all frequencies. Consequently, an external low-frequency source responsible for the reported complaints could not be identified and no regulatory action was warranted.

4.2 Case 2

In this case the annoying low-frequency noise occurred only intermittently and during the on-site campaign it was not perceived by the complainant. Also in this case an industrial plant was suggested as a possible source. A long-term measurement was therefore performed

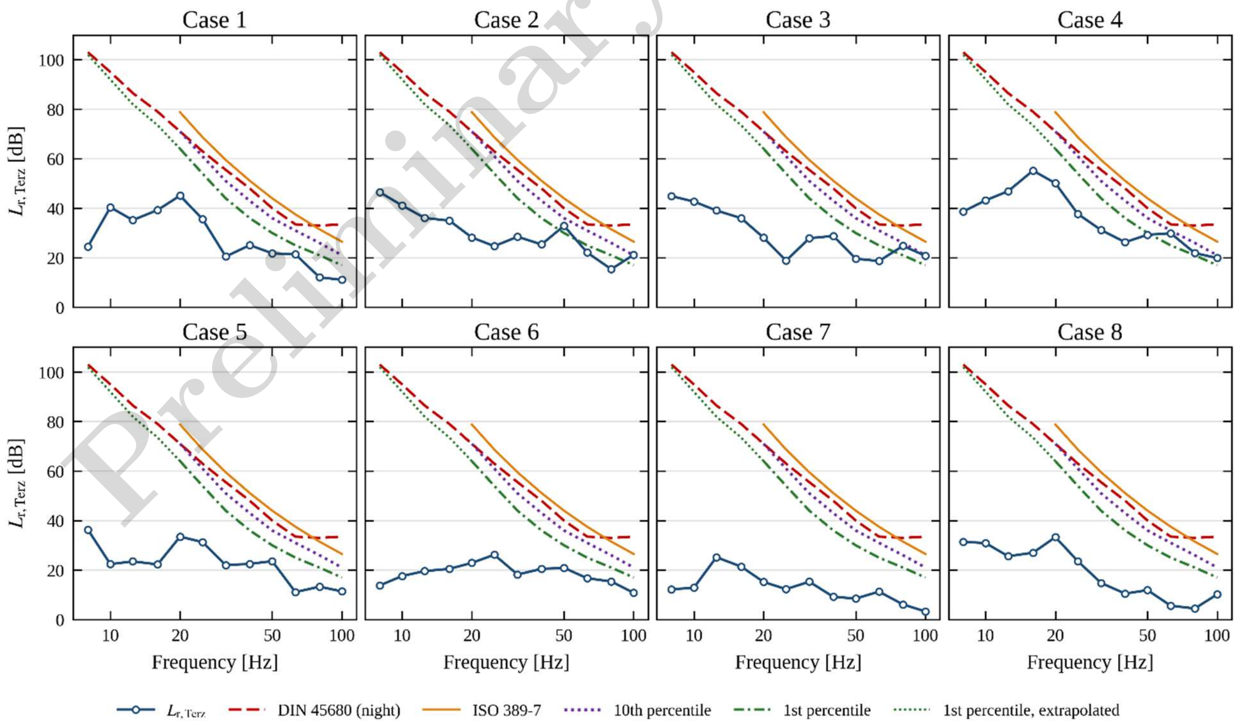

Figure 1: Representative selected spectra for case 1 to 8, one-third-octave assessment levels $L_{\mathrm{r,Terz}}$ inside the dwelling, compared with the DIN 45680 night reference curve, the normative hearing threshold following ISO 389-7, and the 1st and 10th-percentile thresholds derived based on ISO 28961.

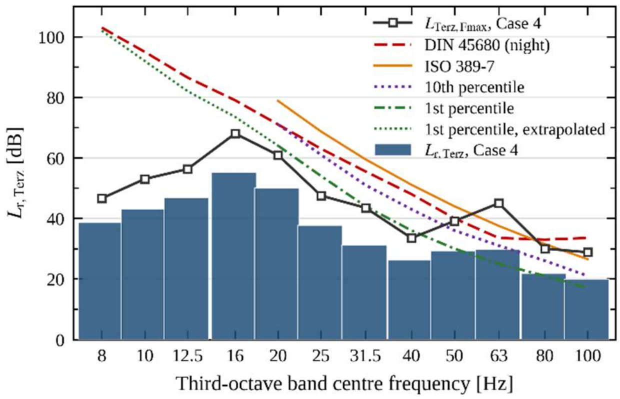

Figure 2: Case 4, one-third-octave assessment levels and maximum one-third-octave levels ($L_{\mathrm{r,Terz}}$ and $L_{\mathrm{Terz,Fmax}}$) in the conservatory. The DIN 45680 night reference values for $L_{\mathrm{Terz,Fmax}}$ are exceeded in this case at 63 Hz.

over six days, with the resident marking the most disturbing intervals via the integrated trigger button. The DIN 45680 low-frequency criterion ($L_{\mathrm{Ceq}} - L_{\mathrm{Aeq}} >$ 20 dB) was met only occasionally, and during night time the one-third-octave assessment levels remained below the DIN 45680 reference values at all times. The perception threshold, however, is reached between 50 and 80 Hz during part of the flagged intervals, whereas the 10th percentile threshold is not reached at any time. During most flagged intervals, elevated A-weighted levels were observed, accompanied by tonal components around 400 Hz in the audible range. The case is therefore better interpreted as an audible-range complaint than as an actual low-frequency noise case.

4.3 Case 3

A complaint in a rural residential area (general residential zone) was associated by the residents with a nearby air-source heat pump. Several such pumps could be identified and were clearly audible outdoors, however, the night-time base level of 35 dB at the property boundary following ÖNORM S 5021 [23] was met.
Indoor measurements yielded $L_{\mathrm{Aeq}} = 13$ dB and the DIN 45680 night reference curve was undercut by more than 10 dB, the 10th percentile threshold was not reached by the assessment levels. The 1st percentile perception threshold was reached at 80 and 100 Hz.
Furthermore, outdoors, the suspected heat pump showed an intermittent operation pattern that did not correlate with the continuously perceived indoor noise reported by the residents. Consequently, the suspected heat pumps could not explain the perception pattern described by the complainant.

4.4 Case 4

The second heat-pump-related case concerned a dwelling in a pure residential zone. The low-frequency noise was continuous and, after some time spent in the quiet environment, perceptible to the measurement technicians in an attached conservatory ($L_{\mathrm{Aeq}} = 22$ dB). Indoor living spaces were exceptionally quiet, with $L_{\mathrm{Aeq}} = 9$ dB measured in the living and sleeping rooms, where the DIN 45680 reference values were undercut by a wide margin. In the conservatory, the one-third-octave assessment levels $L_{\mathrm{Terz,r}}$ still undercut the DIN 45680 night reference. The maximum one-third-octave levels L_{TerzFmax}, however, exceed the DIN 45680 reference values for the maximum level at 63 Hz and even the normative hearing threshold following ISO 389-7, as evident from Figure 2. Whether the conservatory qualifies as a protected indoor space under DIN 45680 is debatable, since its acoustic decoupling from the exterior is considerably weaker than that of conventional living rooms.
Independently of this discussion, a base level of 35 dB was measured at the property boundary, exceeding the 30 dB ÖNORM S 5021 night-time value for pure residential zones. Regulatory action was therefore clearly warranted in this case. Eventually, it turned out that the night-time low-noise mode of the heat-pump at the neighbor property was not set correctly.

Table 1: Selected parameters for the eight investigated cases, taken from reference [7]. The measured A-weighted sound pressure levels L_{Aeq} are listed. The condition for low-frequency noise according to DIN 45680 is met in about half of the cases. Values of L_{Geq} are given where a measurement was possible, the reference value of $L_{\mathrm{Geq}} =$ 85 dB is not reached in any case.

#	L_{Ceq}–L_{Aeq} > 20 dB	L_{Aeq} [dB]	Min. margin $L_{Terz,r}$ vs DIN 45680 (night)	L_{Geq} [dB]
1	yes (26)	12	12 dB @ 63 Hz	55
2	yes, occasionally (long-time measurement)	10–50	~6 dB @ 50/63 Hz	49
3	yes (24)	13	8 dB @ 80 Hz	50
4	yes (27)	22	4 dB @ 63 Hz	65
5	no (18)	14	16 dB @ 50 Hz	44
6	no (15)	13	17 dB @ 63 Hz	–
7	no (17)	10	22 dB @ 63 Hz	–
8	no (19)	11	23 dB @ 100 Hz	44

4.5 Cases 5 to 8

A substantial fraction of all registered cases is characterized by unspecific complaints. The dwellings in these cases are situated in quiet neighborhoods, with no obvious candidate for a possible LFN source. In the example shown here, the residents reported a severe and almost unbearable low-frequency exposure, yet the measured assessment levels lay well below the 1st percentile perception threshold across the entire 8 to 100 Hz range. On statistical grounds, an external sound source is therefore unlikely even for listeners at the sensitive end of the normal distribution. Internal auditory perceptions, such as tinnitus, offer a plausible explanation in these cases [3], [5], [6], [24], [25]. An individual medical clarification, however, lies beyond the scope of the present study carried out by local environmental authorities.

5. Discussion

Compared to alternative international standards, DIN 45680 [8], [9] offers relatively strict reference values for the assessment of low-frequency noise complaints. However, the results show that additional criteria are useful from a practical perspective in order to assess whether an external source is likely to be responsible for the low-frequency sound percepts. The presented analysis therefore compares the measured spectra with the 1st and 10th percentile hearing thresholds and evaluates the G-weighted infrasound level L_{Geq}.

The DIN 45680 low-frequency criterion was fulfilled in only four of eight cases (see Table 1), and in most of the investigated cases the measured spectra remain below the extended assessment criteria, indicating that low-frequency noise, caused by a real external sound source, is unlikely to be the dominant cause of the reported perception. The DIN 45680 reference values for $L_{\mathrm{Terz,r}}$ are not reached by the assessment levels in any case, with a closest approach of 4 dB, and the 10th percentile threshold is likewise not reached. The G-weighted levels range from 44 dB to 65 dB and thus remain far below the Danish criterion (85 dB), so that a relevant contribution of infrasound can be excluded throughout. Note that the 1st percentile perception threshold is reached or exceeded in three cases, exclusively in the bands from 50 Hz upward, that is, in the transition region from low-frequency to audible sound. This is in good agreement with the findings of reference [3]. In one case the DIN 45680 reference values for the maximum level L_{TerzFmax} were exceeded. This observation is accompanied by exceeded traditional assessment criteria [23] that hold for the respective residential zone, and a nearby heat pump could be identified as source.

In two of the eight cases, case 2 and case 8, the complaints could be attributed to noise in the audible range rather than to actual low-frequency components. Note that this is revealed only by an analysis that extends beyond the frequency range covered by DIN 45680. From the perspective of an environmental authority the finding is relevant, since it supports the current efforts of German environmental authorities [4], which identify public information as a possible strategy for responding to complaints, in particular, in cases where no external source can be identified.

In the majority of cases unusually quiet conditions were found in the affected dwellings, with L_{Aeq} below 15 dB and in part below 10 dB. Considering the description of the perceived noises by the residents, typically described as a clearly audible humming noise, this is a remarkable observation. It is concluded that such low background levels remove the masking effect that is usually present in everyday acoustic environments and may render auditory phenomena perceptible that would otherwise be inaudible.

The same effect is illustrated from a different angle by case 4, which concerns an air-source heat pump. It shows that, in principle, weak and low-pass-filtered exterior sounds can combine with a low indoor background level, which can lead to audible indoor contributions even where applicable emission limits are met. It should be noted, however, that from a community noise perspective there is no right to absolute silence, but only to compliance with the limits that follow from the applicable legal regulations [7].

For a subset of the complaints, the measured spectra lie so far below any plausible perception threshold that an external physical cause is unlikely even for listeners at the sensitive end of the normal distribution. In such cases, internal auditory perceptions related to objective or subjective tinnitus offer a more plausible explanation. Percepts of this kind have been discussed as phantom sounds that are not recognized as internal by the affected persons [24], and it is noted in this context that tinnitus-like sensations are readily reported by normally hearing persons placed in very quiet surroundings [25]. The externalization effect could explain the fact that the complainants are convinced that an external sound source is responsible for their perceptions. A recent study of persons reporting a low-frequency sound percept [3] found that their low-frequency hearing thresholds are in general not unusually sensitive, which argues against hypersensitivity as a common explanation.

It has to be kept in mind that the present sample is small and confined to complaints that can be related to an authorized installation, since only these give rise to a formal assignment [7]. The findings are therefore representative of the cases investigated by environmental authorities rather than of low-frequency sound percepts in general. Furthermore, the assessment rests on a limited number of measurement points per case, which were selected in accordance with DIN 45680 to represent the positions reported as most affected by the complainants. At the encountered levels between L_{Aeq} = 9 dB and 15 dB the measurement chain approaches its self-noise floor, which is the reason for the use of a low-noise microphone in the present work.

6. Conclusions

The present study reports on eight low-frequency noise complaints registered in Styria between 2021 and March 2024, which were investigated by measurement campaigns within a dedicated project [7]. Only in one case low-frequency noise levels $L_{\mathrm{Terz,r}}$ are observed that come close to the DIN 45680 reference values for significant annoyance and that exceed those for the maximum level $L_{\mathrm{Terz,Fmax}}$. In this case the origin of the complaint is traced back to a heat pump in the neighborhood. In addition, an exceedance of the night-time base level at the property boundary was found in this case. In two further cases the complaints were attributable to noise in the audible range rather than to actual low-frequency components.

To account for individual differences in low-frequency hearing sensitivity, the assessment was complemented by comparison with statistical hearing-threshold curves derived using ISO 389-7 and ISO 28961 and by evaluation of the G-weighted infrasound level. In most of the investigated cases the measured spectra lie below these extended assessment criteria, indicating that low-frequency noise is unlikely to be the cause of the reported perception. Infrasound is likewise excluded on the basis of the G-weighted levels. These observations suggest that the unusually quiet conditions found in the affected dwellings themselves contribute to the low-frequency sound percepts [24], in good agreement with recent findings in the field of low-frequency noise research [3].

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