Disturbing effects of low frequency sound immissions and vibrations in residential buildings


NOISE & HEALTH
A Bimonthly Inter-disciplinary International Journal

Abstract

Noise immissions with predominant low frequency sound components may exert considerably disturbing effects in dwellings. This applies in particular to sounds which are excited by transmission of structure-borne noise, and to low frequency sounds emitted by ventilators. Exposed persons usually declare such immissions as being "intolerable" even at very low A-weighted sound levels. If mechanical vibrations in the frequency range below 20 Hz (ground-borne vibrations) affect dwelling rooms, the annoying effects are perceived only by a small portion of exposed individuals as a physical effect. For the most part the immissions are observed as vibratory effects on the building and on objects inside the dwelling. The disturbing effects of vibration frequencies above 20 Hz (structure-borne sound) are determined by the airborne sound field generated inside a particular room and its given surface and extension.

EXCERPTS

Introduction

As early as in the seventies, sound level measurements carried out to verify complaints about annoying noises in dwellings have shown the following: Noises which in many cases induced vehement complaints were to a large extent of rather low sound levels, whereas the effects of simultaneous other noise immissions of higher sound levels like the ticking of a clock or intermittent traffic noise did not cause annoyance (Findeis and Thielebeule, 1979).

These findings gave rise to investigations designed to answer the following questions:

1) Are the differences in the perception of different noises just accidental occurrences, or do they follow a systematical pattern?

2) Which noise characteristics are responsible for differences in noise perception?

In order to clarify these questions the complaints were therefore analysed, on the one hand by evaluating spontaneous statements on the effects of noise immissions by the persons involved, and on the other hand by taking measurements of A-weighted noise levels and additionally carrying out acoustical measurements. The same method was used in cases of vibrations.

Method

As a first step in answering question (1) quoted above, the measured values obtained from the initial input evaluation were categorised according to their sources:
* Measured values of road traffic noise

* Measured values of ventilator noise

• Measured values of other airborne transmitted sounds

* Measured values of airborne sounds emanating from structure-borne sound immissions.

In most cases, structure-borne sound sources were circulator pumps in heating systems and other technical building equipment, refrigerators and ventilators in commercially used premises of dwelling buildings.

Secondly, the distribution functions of the measuring data regarding the various noises were taken under consideration. Discussion of the results included statements of the affected persons on the respective effects of the immissions.

To clarify question (2) quoted above, lin weighted noise levels were initially assessed in addition to A-weighted levels. The technique of the measuring devices ensured that frequency components distinctly below 20 Hz (infrasound) did not interfere with the measuring results. In addition, third octave sound levels and, in the case of structure-borne sound immissions, also the vibration velocity levels of the indoor wall surfaces were frequently measured.

Parallel to measurements of floor vibrations connected with vibration immissions of frequencies below 20 Hz, not only the statements of the exposed persons regarding the immissions, but also observations made by the persons performing the measurements with regard to the immissions were documented and correlated with the measurement results.

Study results

Airborne sound immissions

Results of measurements and evaluations

The results given in the following are based on the evaluation of measurements gathered in response to 204 complaints about noise disturbance in the city of Potsdam and the western districts of the Federal State of Brandenburg in Germany. [Table - 1] gives the distribution of the statements made in the complaints over the different kinds of airborne sound immissions. Complaints containing several overlapping immissions were not included.

It may be noted that the quota of complaints regarding road traffic noise immissions is relatively small with respect to the large number of persons complaining about the noise immissions under concern. In contrast, the number of complaints about structure-borne sound immissions is surprisingly high.

The sound pressure levels measured for the noise immissions showed, as a rule, a normal distribution of sufficient approximation. The assessed distributions were evaluated following the exemption of that sound level which either exceeded or fell short of 50% of the
measurement values (50%-level). Further, that sound level was determined which fell short of 5% of the measurement values (5%-level), and which may be considered as the immission threshold of complaints regarding the noise in question. The results of these evaluations are listed in [Table - 2]. The traffic noise data are daytime values; night-time values are expected to be lower. The effects of the other noises were of a permanent or intermittent nature day and night.

A t-test with a given error rate of 5% (Sachs, 1984) yielded highly significant differences between outside 50%-levels of road traffic immissions and 50%-levels of other noises. This is also true for 50%-levels of the respective indoor noise. Equally significant, though less distinct, are the differences between mean values of noise levels generated indoors and those from outside. No differences were, however, found between the distributions over daytime and night-time measurement values and the noise of ventilators which only run indoors during the daytime. This also applies to noise initiated by structure-borne noise.

In 58% of exposures to structure-borne sound immission at day and night, the complainants stated sleep disturbances among other reasons. The distribution functions of the respective measuring values did not differ from the remaining measuring values of this kind of noise.

In summing up, the answer to question (1) quoted above is that particularly indoor ventilator noise as well as noises generated by structure-borne sound transmission exert distinctly higher disturbing effects than road traffic noise.

First causative indicators of increased annoyance due to these noises are considerable differences in levels $L_{in} - L_A$ which prove to be distinctly higher with regard to indoor levels compared with outdoor levels. They suggest rather strong effects of noise components of frequencies below 100 Hz.

Out of 33 frequency analyses carried out for indoor noise, 31 exhibited predominating octave and third octave band levels between 20 and 100 Hz. Ten out of twenty third octave band level measurements additionally showed tonal components because there appeared third octave band levels which surplussed adjoining third octave band levels by at least 5 dB (DIN 45680, 1997). In parallel, and to a similar extent, spatial level fluctuations were assessed in the rooms, indicating the presence of stationary waves.

Vibration measurements taken in relation perpendicular to the wall in cases of structure borne sound immissions had the following results: In the majority of cases the vibration velocity levels $L_v$ as related to $v_c = 5 \cdot 10^{-8}$ m/s were near to identical with the airborne sound level assessed inside the room. In several cases airborne sound levels exceeded the structureborne sound levels by up to 10 dB.

If vibrations of the wall surfaces inside a room are, according to (Cremer and Heckl, 1967), assumed to be bending waves, then this mechanism principally suggests a tangential radiation of airborne sound is from the vibrating walls. This again enhances the development of stationary waves in closed rooms.

The close association between vibrations and airborne sound immissions in dwelling rooms and their respective effects may be illustrated by the following case report:

A compressor unit was causing extreme annoyance to the occupants of a flat within a distance of 50 m, complaining about "vibrations". Vibration measurements of the floor and the walls exhibited a vibration velocity of 0.1 mm/s, or other a vibration velocity level of 66 dB with a frequency of 33 Hz.
Vertical vibrations of this magnitude are as a rule not perceptible as ground-borne vibrations. For this reason, the strong vibrations of the window panes remained inexplicable at first. Then the problem was then solved by measuring the airborne sound levels in the same room which yielded the following results:

In the centre of the room 26 dB(A) resp. 66 dB(lin), and near to the wall surfaces 44 dB(A) resp. 84 dB(lin).

The exposed persons stated that the vibrations near to the walls left an uneasy feeling in their stomachs which very quickly increased to the point of feeling sick. The measuring staff experienced similar symptoms. The highly exceeding level values near the to walls were in all probability promoted by the fact that the distance between the window and the opposite wall was 5 m which was equal to exactly half the wave length of the airborne sound, or resonance.

The severe effects of these low frequency stationary airborne sound waves could, according to the statements of the measuring team, not be explained by auditory sensations alone.

Question (2), quoted above as to specific characteristics of the most disturbing noise immissions in dwelling rooms, can according to the given results be answered as follows: The main cause of increased disturbances due to the quoted noises obviously consists in the high unweighted sound pressure levels of low frequency noise components. In A-weighted measurements these components remain widely disregarded. An additional characteristic increasing the annoyance seem to be narrow banded noise components which in closed rooms are often associated with the development of stationary waves. The effect of airborne soundinduced stationary waves on the exposed persons seems to represent a specific factor of the annoyance effect.

**Disturbing effects of noise immissions**

In the preceding paragraphs it has been pointed out that as regards noise immissions with a considerable proportion of low frequency sounds in private dwellings, more than half of the complaints were made on the grounds of sleep disturbance. Quite often symptoms like “a roaring in the head, especially when lying down” were brought forward. Time and again, "a feeling of riding a lift" was reported, and over and again the measuring team had the impression that the reported immissions meant a nerve-racking experience for the exposed persons. Several complainants even got into a state of being aggressive. There were reports by a number of trustworthy persons on how they at first - for instance when moving into the flat - did not even notice any immissions. But in the course of a few weeks they began to perceive them distinctly and became intolerable after continued exposure. It was obvious that in these cases a sensibility of specific noise components had developed. Thus, it is understandable that non-exposed persons were at a difficulty to even acknowledge such noise immissions.

**Excitation of vibrations by airborne sound**

Apart from sound emissions of vibrating building elements, secondary phenomena were induced in some cases by very strong low frequency airborne sound immissions which are typical of ground-borne vibration immissions (see section on 'Ground-borne vibration immissions'). We may point out the clattering of glass panes in cupboards and of doors in their locks. In an dwelling situated above a discotheque not only the airborne sound immission was assessed but in addition the floor vibrations which were clearly detectable as they created an awkward feeling in the feet.
Recommendations on immission assessment

In conclusion of the results mentioned above, when estimating noise immissions from noise sources with a high proportion of strong low frequency sound components, as for instance exhausters, it is advised to take measurements not only from the outside but also the inside of exposed rooms. As a rule it is not sufficient, though, to measure from a random measuring site in a room because, as has been demonstrated, considerable sound level fluctuations due to stationary waves are to be expected. In this context, the respective normative regulations of the German standard DIN 45680 (1997) will be heeded.

Ground-borne vibration immissions: Definition and propagation of ground-borne vibrations

According to the German standard DIN 4150 (1999) ground-borne vibrations are defined as mechanical vibrations of corporeal substances in the frequency range 1 to 80 Hz, with potentially detrimental or annoying effects.

In the paragraph 'Results of measurements and evaluations' it has been demonstrated that according to present experience the essential cause of annoyance, in association with an exposure of the outer walls of a room to mechanical vibrations with frequencies above 20 Hz (structure-borne sounds), is the build-up of an airborne sound field generated by sound emissions into the premises. In the following paragraph, the effects of vibration immissions with frequencies below 20 Hz (ground-borne vibrations in a proper sense) will be discussed.

If from very low-revving machinery very low frequency vibrations are transmitted into the ground, these are known to propagate over rather great distances along the upper layers of the ground.

Such vibrations may induce inclining or shearing vibrations in buildings which as a main effect induce horizontal vibrations of walls and ceilings. The dominating frequencies of such vibrations are generally found in the interval of 3 to 8 Hz. In the case of vertical ceiling vibrations, the frequency range was from 8 to 22 Hz. The immission circumstances were in most cases influenced by resonance phenomena.

Horizontal ceiling vibrations at steady time periods

The data given in this paragraph are mainly obtained from vibration immissions caused by running frame saws. As a rule, the immissions affected the dwellings only at certain periods of time during the day, with nearly constant amplitudes.

Based on the statements of the exposed persons and on observations made by the measuring team, together with the results of stationary vibrations of frequencies from 4.5 to 5.5 Hz, [Table - 3] shows the correlations between the magnitude of the vibrations and the disturbing effects exerted by them.

[Table - 3] shows that annoyance due to horizontal vibrations is realised as a body reaction only by a small percentage of exposed persons. A highly disturbing effect is that of the observed effects on the building and household equipment. The same holds for feelings of frightfulness. In some cases, vibrations aroused alarm as soon as ripples appeared on the otherwise smooth surface of fluids or when indoor plants started trembling.
Traffic induced vibrations

Road traffic induced ground-borne vibrations are likely to cause extreme annoyance, especially in parts of Northern Germany which are geologically marked by the glacial epoch. Ground-borne vibrations excited by road traffic are equally assessed and evaluated according to DIN 4150 (1999). There is some difficulty because the normative regulations do not specifically include the estimation of stochastically occurring vibrations. In addition, road traffic induced ground-borne vibrations are established between "singular vibrations" (by bus traffic regarding low traffic residential sidestreets) and approximately "constant ground-borne vibrations" (from near-by highway) (Peters, 2001).

In the Federal State of Brandenburg, more than 100 measurements were carried out during the last 10 years. In most cases, vertically oriented vibrations were predominant. The maximum values obtained were of a weighted vibration severity $KB_{F_{\text{max}}}$ ranging between 0.04 and 4.1, or r.m.s. values of the evaluated vibration severity $KB_{F_{\text{tm}}}$ (DIN 4150, 1999) ranging between 0 and 1.23. There is a fixed relation between the two quantities $KB_{F_{\text{tm}}}$ and $KB_{F_{\text{max}}}$ (Peters, 2001). A spasmodic increase of complaints occurs between $KB_{F_{\text{tm}}} = 0.10$ and 0.13. As regards road traffic, the values are $KB_{F_{\text{max}}} = 0.4...0.6 \cdot v_{\text{max}}$

Road traffic induced ground-borne vibrations are generally associated with road traffic noise. At present, the general state of knowledge about combined effects of ground-borne vibrations, direct airborne sound and structure-borne sound radiated by the wall or floor, low frequency sound and noticeable vibrations of objects or their audible noises and other effects (as for instance shadow phenomena of passing-by heavy-load lorries) is small. But it is the combined effects of the quoted disturbing factors which makes up the grade of total disturbance in a residential area. Only with these factors in mind complaints lodged for ground-borne immissions with measuring values below the threshold of perception $KB = 0.1$ can be explained.

In addition, complaints about road traffic induced ground-borne vibrations are quite often influenced by concerns about possible damage to one's own dwelling due to road traffic. In the majority of inspected damages such as ruptures or enlarging ruptures there were, however, other causes such as an acute lowering of the groundwater level or deficiencies in building construction had to be made responsible.

Delimitation of vibration perceptions in rooms

According to the observations quoted above, [Figure - 1] gives the following grades of differently perceived vibrations in rooms, depending upon their frequency and magnitude.

It is emphasised that in the frequency range above approximately 20 Hz there may occur, due to sound radiation from the inner wall surfaces of a room, highly disturbing effects even if the magnitude of the vibrations is distinctly below the perceptive threshold of humans. According to the observations as demonstrated, these immissions ought to be given special attention in the future.[7]
