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# OCJENA IZLOŽENOSTI LJUDI VIBRACIJAMA I BUCI U ZGRADAMA ZA STANOVANJE

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***Abstract:***

Zgrade namijenjene za rad i stanovanje mogu biti pobuđene na vibracije djelovanjem različitih pobudnih izvora koji se mogu nalaziti unutar ili izvan samog objekta. Strukturne vibracije u zgradama mogu izazvati osjećaj neugode i umanjiti komfor kod stanara, kao i efikasnost osoba koje koriste radne prostorije u zgradi. Neki izvori vibracija mogu djelovati na način da proizvode i dodatne efekte, npr. strukturni zvuk ili zvuk koji se prenosi vazduhom, zveckanje prozora i drugih predmeta u objektu. Standard ISO 2631-2 definiše metodologiju ocjene izloženosti ljudi vibracijama u zgradama, ali ne propisuje granične vrijednosti vibracija kojima mogu biti izloženi stanari ili korisnici zgrada, kao što je slučaj i sa većinom nacionalnih propisa u ovoj oblasti. Za razliku od vibracija u zgradama, nacionalni propisi ograničavaju nivo zvuka koji se emituje u životnoj sredini. U ovom radu prikazan je postupak ocjene izloženosti ljudi negativnom djelovanju buke i vibracija u zgradama, kao i detaljna analiza slučaja u vezi s tim.

*Keywords: vibracije u zgradama, buka, izloženost ljudi, metode ocjene.*

# ASSESSMENT OF HUMAN EXPOSURE TO VIBRATION AND NOISE IN RESIDENTIAL BUILDINGS

***Abstract:***

Vibration in buildings may occur from different external or internal sources. Where occupants can detect vibration in buildings, it may potentially impact their comfort or working efficiency. Some vibration sources give rise to audible effects such as structure-borne noise and airborne noise, and secondary rattling of building elements or contents. The international standard ISO 2631-2 concerns human exposure to whole-body vibration in buildings, but like most national standards, it doesn't prescribe the permissible vibration amplitudes with respect to the comfort and annoyance of the occupants. Contrary to vibration standards, the national regulations concerning environmental noise prescribe the limits of allowed sound intensity in residential and office premises. This paper gives an overview of the process used to assess the influence of vibration and noise on humans in buildings. Also, a detailed case study regarding adverse comment due to noise and vibration in building is shown.

*Keywords: building vibration, noise, human exposure, assessment methods.*

# 1. INTRODUCTION

Occupants can detect structural vibration in buildings and can be affected by them in many ways. Their comfort and quality of life can be reduced as well as their working efficiency [1]. In contrast, it is well known that people tolerate much higher vibration magnitudes in vehicles than in buildings, because vibrations have different frequency range in these two cases. Vibration in building that can be perceived by humans remain in the low- frequency range, close to the frequencies of human body internal organs [2]. Human response to vibration in buildings is very complex. The basic human response to vibration in buildings is adverse comment, which depends on specific circumstances. In most cases, the degree of annoyance and complaint cannot be explained purely by the magnitude of monitored vibration. An analysis of these complaints shows that other parameters related to vibration source (for example work time) or produced by vibration in exposure area (noise) may also give an explanation of the complaints [3, 4]. Vibration sources inside and outside buildings may generate human whole-body vibration, together with the parallel effects, such as structure-borne and airborne noise, induced rattling, movement of furniture and other object, as well as visual effects [5, 6]. The most well-known standards for measurement and evaluation of human exposure to whole-body vibration are ISO 2631–1 (1997) and BS 6841 (1987). Although BS 6841 (1987) was developed as a British standard, it has been used extensively (often in preference to ISO 2631–1, 1997) outside Britain [2]. Some researchers made comparison between standards related to human perception of whole-body vibration in building [7] only quoting the provisions in the standards. Some authors made comparative analyzes between different standards, regarding particular parameters for assessing the influence of vibration on humans, the range of considered frequencies, duration of vibration, signal processing and general approach to the problem [8, 9].

# 2. HUMAN RESPONSES TO BUILDING VIBRATION

In residential buildings, adverse comment regarding building vibration is probably when the vibration levels are slightly above the threshold of perception. In general, acceptable levels are likely to be related to general expectations of the occupants and are not determined by any other factor such as health hazard in short term or working efficiency.

Thresholds of perception for continuous whole-body vibration vary widely among individuals. Approximately half of the people in a typical population, no matter standing or seated, can perceive a vertical weighted peak acceleration of 0.015 ($m/s^2$). A quarter of the people would perceive a vibration of 0.01 ($m/s^2$), but the least sensitive people would only be able to sense a vibration magnitude of 0.02 ($m/s^2$) or more. Threshold of perception is slightly higher for vibration duration of less than about one second [3, 5].

## 2.1. CHARACTERISTIC OF BUILDING VIBRATION

Parameters to be considered in vibration analysis are as follows: characteristic of vibration sources, nature of the vibration time history, exposure time to vibration, associated phenomena, i.e. parallel effects. When it vibrates, a building may move as an entity on its foundations (at very low frequencies, up to a few Hz), or individual buildings components, such as floors, may perform their own vibration movement (at higher frequencies, ranging from a few to tens of Hz). The magnitude and direction of vibration will depend on the location in the building.

#### 2.1.1. Sources of building vibration

Vibration in buildings can be caused by different external or internal sources [6].
External vibration sources include:

- traffic (road and underground traffic),
- industrial sources (e.g. presswork),
- construction or demolition works.

This vibration is transferred to a building through the ground, and vibration passing into the building depends on the transfer function between the ground and the building. The dynamic characteristics of a building (eigenvalues) can cause higher vibration levels at some specific frequencies due to resonance. The wind and external airborne acoustic excitation can also generate building vibration.
Internal sources of vibration can be divided into:

- mechanical excitation (e.g. lifts, air-conditioning or ventilation plants, heavier office machinery, washing machines, vacuum cleaners, etc.),
- human induced excitation (walking, jumping, dancing, etc.).

Mixed-use buildings can undergo specific problems, where vibrations caused by human activities in one part of the building are transmitted to more sensitive areas in another part of the building.

#### 2.1.2. Nature of vibration time history

The time history of vibration can be [4, 6]:

- continuous - uninterrupted vibration for the assessment period, daytime or night-time,
- intermittent - perceived in separately identifiable repeated periods,
- occasional - occurring less frequently than intermittent and it is less predictable,
- impulsive - it is a rapid built-up to a peak followed by a damped decay, that might or might not involve several cycles of vibration.

Each of these types of time history can have a constant or variable amplitude.

### 2.2. FREQUENCY WEIGHTING

The way in which humans perceive vibration depends on different factors, including the vibration frequency content and direction. People are most sensitive to whole-body vibration within the frequency range of 1 to 20 Hz, but there are different human sensitivities to vibration in different directions of excitation. Because of that, different frequency weightings of measured acceleration magnitude are required for the different axes of vibration. The directions of vibration are related to the structure rather than to the human body. The orientation of the structure-related coordinate system shall be as for a standing person, as shown in Fig. 1.

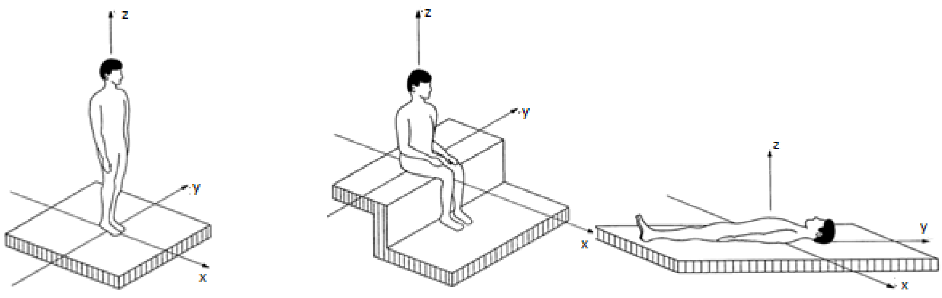


*Figure 1. Direction of coordinate system for mechanical vibration influencing humans in buildings [5]*

Regarding this issue, different countries have different regulations specified in standards. For example, the international standard ISO 2631-2 [4] specifies the use of the frequency weighting $W_m$, Fig. 2, which is applicable in the frequency range 1 Hz to 80 Hz, where the posture of an occupant does not need to be defined. This frequency weighting is irrespective of the measurement direction.

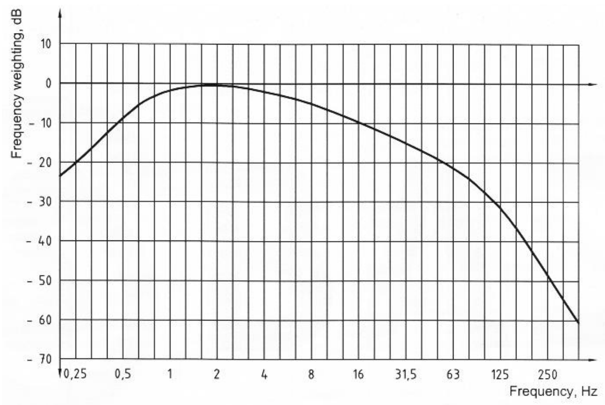


*Figure 2. Frequency weighting $W_m$ , with acceleration as the input quantity [4]*

On the other hand, British standard BS 6472-1 [6] specifies that different frequency weightings of measured acceleration magnitude are required for the different axes of motion. The frequency range concerned is 0.5 Hz to 80 Hz for the three translational axes: fore-and-aft, lateral and vertical, Fig. 1. The weighting curve modulus $W_b$ for vertical acceleration is shown in Fig. 3a, and weighting curve modulus $W_d$ for horizontal acceleration is shown in Fig. 3b. The weightings demonstrate maximum sensitivity to vertical acceleration in the frequency range 4 Hz to 12.5 Hz and to horizontal acceleration in the range 1 Hz to 2 Hz. The weighting $W_b$ is the most appropriate frequency weighting for use with vertical vibration when the levels of vibration are clearly above the threshold of perception.

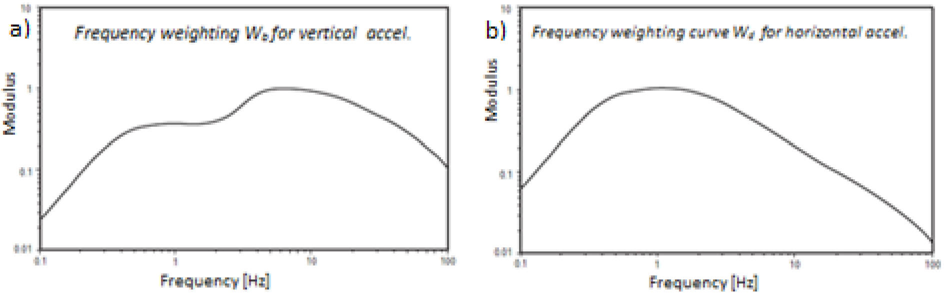


*Figure 3. Frequency weighting curves according to BS 6472-1 [6]*

## 2.3. MEASUREMENT OF BUILDING VIBRATION

The ability of a person in a building to sense vibration depends on what he/she is doing, where he/she is positioned in the building, how he/she is coupled to the building, as well as on the dominant direction of the vibration. A person who is moving is less sensitive to vibration than a person who is seated. The coupling is the most direct when the person is standing on the floor. If the person is seated, the coupling is less direct and the seat structure may dampen vibration. In some situations, a bed structure can amplify the vibrations received from the building.

### 2.3.1. Direction of measurement

The vibration should be measured in all three orthogonal directions simultaneously using triaxial transducer. If the direction of the dominant vibration is known, the motion may be measured uniaxially along the axis in which the weighted acceleration amplitude is the greatest. Transducer should be mounted so as to truly reflect the motion of the object or surface being measured [3].

### 2.3.2. Location of measurement

The main goal in the selection of the measurement location should be to establish the vibration level at the point of entry to the body. However, that particular location is slightly possible to be identified. So, the vibration should be measured on the floor of the room where the highest magnitude of the frequency weight vibration occurs, or on a suitable surface of the building structure. The way in which a floor responds depends on two factors: whether the excitation is external or internal and whether the floor is “low frequency” or “high frequency” [6]. If the excitation of building is external (ground-born vibration), the rigid body motion or the lowest mode of vibration (so called “dish-shaped” mode) will dominate in the floor response. One or two measurement points in the central part within one-third and two-thirds of the width or length are sufficient to determine the vibration response in this case of excitation. If the excitation is internal (e.g. pedestrian footfalls), floor response will vary according to the modal parameters (natural frequencies, mode shapes and damping) of the floor. Assessment should be made at or near the places where the most adverse comment has been generated, with the typical walking path and pacing rate as excitation.

### 2.3.3. Duration of measurement

The duration of measurement should be sufficient to ensure statistical precision and to ensure that the measured vibration is typical of the assessed exposure.

### 2.3.4. Assessment methods

For the evaluation of vibration in buildings with respect to comfort and annoyance, overall weighted values of vibration should be measured. It is preferable to measure vibration in acceleration terms assessed using the frequency weight value r.m.s. (the root mean square value) or the vibration dose value $VDV$, [4].

The international standard ISO 2631-1 defines the r.m.s. method as a basic method of assessment, but notes that sometimes additional methods are required, such as the vibration dose value method, $VDV$, or the maximum transient vibration value method, $MTVV$. The r.m.s. method averages acceleration amplitudes in duration time:

$$a_w = \left[ \frac{1}{T} \int_0^T a_w^2(t)\, dt \right]^{\frac{1}{2}} \tag{1}$$

where:

$a_w(t)$ is the frequency weighted acceleration as a function of time in ($m/s^2$), using $W_m$ weightings,

$T$ is the duration of measurement in (s).

The British standard BS 6472-1 [6] describes how to determine the vibration dose value, $VDV$, from frequency weight vibration measurement. The $VDV$ is used to estimate the probability of adverse comment which might be expected from humans regarding building vibration. The $VDV$ is defined by the relation:

$$VDV_{b/d,day/night} = \left[ \int_0^T a_w^4(t)\, dt \right]^{\frac{1}{4}} \tag{2}$$

where:

$V_{b,d\ day/night}$ is the vibration dose value in ($m/s^{1.75}$),

$a_w(t)$ is the frequency weighted acceleration in ($m/s^2$), using $W_d$ or $W_b$ weightings as appropriate,

$T$ is the duration of measurement in [s].

Where possible, the $VDV$ should be determined from a measurement obtained over the full exposure to vibration, that is 16h for daytime or 8h for night-time period. The $VDV$ method is more sensitive to vibration peaks than the basic method of assessment, using fourth power instead of the second power of the acceleration time history. A doubling or halving of the vibration magnitude is equivalent to an increase or decrease of exposure duration by a factor of sixteen.

After the frequency weight measurement of r.m.s. acceleration or $VDV$ values is completed at the relevant measurement places, their significance in terms of the probability that the determined vibration level might result in "adverse comment" by those who experience it, can be derived from Table 1. and Table 2. These values represent the best judgment currently available and may be used for both vertical and horizontal vibration.

There is no exact definition of the term "adverse comment" in standards dealing with building vibration. It can be realized as a technical rather than legal term. Adverse comment is just the way by which occupants express negative responses to vibration.

Table 1. *The frequency weighted r.m.s. acceleration ($m/s^2$) corresponding to a low probability of adverse comment [6]*

| Place | Exposure periods | | | | |
|---|---|---|---|---|---|
| | 16 h | 1 h | 225 s | 14 s | 0.9 s |
| Residential buildings 16 h daytime | 0.01 to 0.02 | 0.02 to 0.04 | 0.04 to 0.08 | 0.08 to 0.16 | 0.16 to 0.32 |

Table 2. *The $VDV$ values ($m/s^{1.75}$) which may result in various probabilities of adverse comment within residential buildings [6]*

| Place and time | Low probability of adverse comment $VDV$ ($m/s^{1.75}$) | Adverse comment possible $VDV$ ($m/s^{1.75}$) | Adverse comment probable $VDV(m/s^{1.75})$ |
|---|---|---|---|
| Residential buildings 16 h daytime | 0.2 to 0.4 | 0.4 to 0.8 | 0.8 to 1.6 |
| Residential buildings 8 h night-time | 0.1 to 0.2 | 0.2 to 0.4 | 0.4 to 0.8 |

## 2.4. PARALLEL EFFECT TO BUILDING VIBRATION

Human reaction to building vibration may also depend on related effects which occur at the same time with vibration. Thus, it is necessary to consider all parallel effects such as structure-borne or air-borne noise, induced rattling and visual effects [4, 6].

### 2.4.1. Structure-borne noise

Vibrations of building structures generate noise which can be heard within the building, whether they are caused by ground-borne vibrations, acoustic excitation from external sources or from some internal sources. The typical characteristic of structure-borne noise is the low-frequency noise in the frequency bandwidth below 100 Hz (for example noise from underground trains, or same internal sources in building).

Structure-borne noise should be measured at the location in the room where its effect is considered to be most disturbing. Very often, it is covered by ambient noise from other sources which creates difficulties in its definite determination.

### 2.4.2. Airborne noise

Airborne noise heard in building at the same time as vibration is felt might be related to the vibration source. The presence of noise at the same time with the vibration might affect a person’s response. In this situation airborne noise could be measured.

Also, the low-frequency airborne noise can be an issue in vibration-related complaints. Typical source of low-frequency airborne noise is the air-conditioning and ventilation system in building. Care should be taken to distinguish between vibration and low-frequency noise.

#### 2.4.3. Induced rattling

The building vibration might cause a parallel effect such as rattle of windows, furniture or ornaments. Their occurrence might emphasize the presence of vibration.

#### 2.4.4. Visual effect

In the case of low-frequency vibration (less than 5 Hz) visual effects may be observed, such as the swinging of suspended features. These factors may emphasize the disturbance and annoyance caused by vibration.

## 3. ASSESSMENT OF NOISE IN BUILDING

The national standard regarding building acoustics JUS U.J6.201 [11], as well as the Rulebook on permissible limits for the intensity of environmental sound and noise [12] in our country, specify the permissible noise levels in rooms in residential buildings, which should not be exceeded, as shown in Table 3.

Table 3. *Permissible equivalent sound pressure level [11]*

| Permissible noise level in rooms in residential buildings 15 min $L_{AeqT}$(dB) | | |
|---|---|---|
| Noise source criterion | Daytime (6:00 – 22:00) | Night-time (22:00 – 6:00) |
| Noise originating from service rooms in building (heating plant substation, transformers, elevators, etc.), home installations (water supply, sewage, etc.) and devices in adjacent flats (various machines and home appliances), as well as noise emitted by stationary sources outside building | 40 | 30 |
| Noise originating from non-stationary sources outside building (e.g. traffic) | 45 | 35 |

According to ISO 1996-1 [14], the parameter for noise assessment is the A-weighted equivalent continuous sound pressure level measured over time interval of T=15 minutes, $L_{AeqT}$, defined by the equation:

$$L_{AeqT} = 10\log\left[\frac{1}{T}\int_T \frac{p_A^2(t)}{p_0^2}dt\right] \tag{3}$$

where:

$p_A(t)$ is the A-weighted instantaneous sound pressure at running time $t$,

$p_0$ is the reference sound pressure (=20 μPa),

$T$ is the duration of measurement.

Generally, noise generated by building services is a significant problem. Building services can generate noise via airborne or structure-borne paths or both. The amount of structure-borne noise can be reduced by increasing the vibration isolation in a system. That can be done by different sound protection measures [13]:

- Reduction of the structure-borne noise transmission from the tube material to building construction - this is achieved by mounting the tube using elastic elements. By the soft plastic insert, the direct contact between the tube material generating the sound energy and building construction are eliminated, minimizing the radiation of noise from installations through the building construction to the airspace of the room where the noise could be heard.

- Attenuation of the sound energy extending along the tube - this is achieved by inserting the elastic couplings made of rubber into the tubing. This separates the part of the installation which contains some dominant noise source from the rest of the installation which passes near the places to be protected from noise.
- Attenuation of the sound energy extending through fluids - this is achieved by installing a dampener in the ventilation and air conditioning tubes, which can weaken the noise extending along the tube.

## 4. CASE STUDY

### 4.1. PROBLEM DESCRIPTION

The case of occupant's adverse comment to noise and vibration problem in a one-room apartment (studio) located in a mixed-use building (residential/business) in the center of Banja Luka has been analyzed, [10]. According to the national regulations [12, 15], there are six acoustic zones that are distinguished regarding their purpose and permissible levels of outside noise: I) hospital, medical; II) tourist, recreational; III) purely residential, educational, health institutions, public green and recreational areas; IV) commercial, commercial-residential, warehouse without heavy transport; V) business, administrative, commercial, crafts, service; VI) industrial, warehouse, service and traffic area without housing. The analyzed building is located in the acoustic zone IV, in the vicinity of a very busy city street, figure 4a. The apartment is positioned on the first floor, above office rooms which are located in one part of the ground floor and the basement of the building.

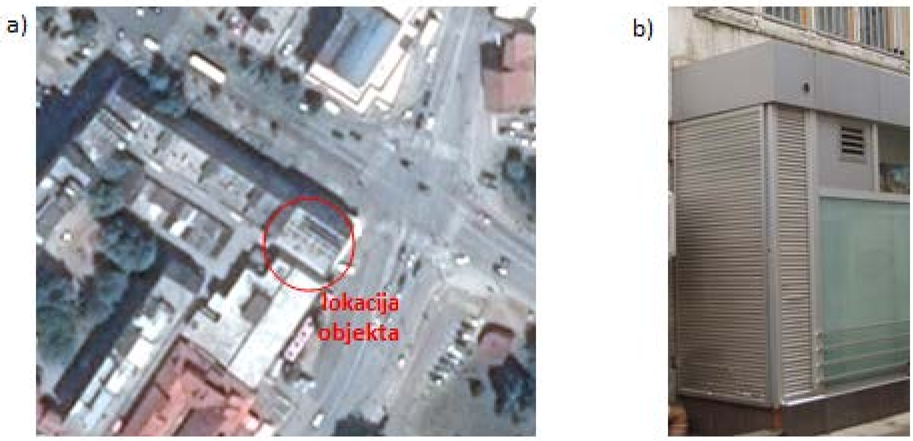


*Figure 4. a) location of building, b) chamber enclosing the exterior units of the air-conditioning system*

The occupants complained about discomfort caused by a continuous sound heard after the reconstruction of the ceiling in the office rooms below the apartment. The aim of that reconstruction was the installation of the air conditioning system and the ventilation (airing) in the office rooms. The three exterior units of the cooling system, so called "split" air-conditioner system, are located on the outside wall of the building (under the windows of the apartment being considered) and enclosed in a special chamber made of sheet metal panels, Figure 4b. This space also enclosed the ventilation exhaust ducting from the toilet located in the basement of the office, with built-in ventilator for forced circulation.  Also, there is the exhaust of the ventilation ducting from the office ground floor. Apart from the assumption that unpleasant sound comes from the air-conditioning and ventilation system, it has been taken into account that there is a heating plant substation in the other part of the building's basement and that no noise had been heard before the reconstruction of the ceiling which can be related to that substation.

The assumption is that annoying and unpleasant sound represents the combination of the structural-borne and airborne sound generated from these installations.

### 4.2. MEASUREMENT METHODOLOGY

#### 4.2.1. The measurement of noise

In order to determine the sound level, the 15-minute A-weighted equivalent continuous sound pressure level, $L_{AeqT}$, was measured during daytime (6:00-22:00) and night-time (22:00-6:00), as specified in [12, 16] .

The following measurement equipment was used for this investigation, Figure 5:

- Portable Pulse type 3560 C, by Bruel&Kjaer,
- Free field microphone, type 4191, and pre-amplifier, type 2669, by Bruel&Kjaer,
- Overall level analyzer for the Portable Pulse, that meets the requirements of class I instruments according to IEC 651, 1979, for noise meters,
- Noise calibrator, type 4231, by Bruel&Kjaer (calibrator's sound level 94 dB at frequency of 1 kHz).

*Figure 5. Multi-analyzer Portable Pulse type 3560 C and free field microphone with pre-amplifier*

Although the names of the parameters measured by the Portable Pulse differ from the names of the parameters measured by standard sound level meters (e.g. sound level meter 2260 Investigator, by Bruel&Kjaer), essentially they are the same parameters. A comparative overview of these parameters is given in Table 4.

Potential noise sources were classified as follows:

- noise sources inside the building are machine installations in the office area (heating, ventilation and air conditioning installations),

- stationary noise sources outside the building are the air conditioners installed under the apartment window,
- source of non-stationary sound outside the building is traffic.

Table 4. *Comparative overview of parameters for Portable Pulse and Investigator*

| | Portable Pulse 3560 C | 2260 Investigator |
|---|---|---|
| Peak sound pressure value | Peak Time History (using 1s peak interval) | Peak (1s) |
| Equivalent continuous sound pressure value | Linear | LEQ |
| Equivalent sound pressure value with impulse | Linear + Impulse | LIm |
| Instantaneous sound pressure value | Exponential | INST |
| Maximum instantaneous sound pressure value | Exponential + Max. | Max. L. |

Measurement conditions are defined in such a way that measurement was performed in the apartment with closed windows and closed entrance door of the apartment. The only room of this apartment has the function of the living room and the bedroom, thus it falls under the noise sensitive room category. The room is furnished with ordinary furniture pieces (dresser, sofa bed, table and chairs, refrigerator and freezer, TV set), the floor is wood parquet covered with a carpet. During measurement, a constant non-stationary traffic noise was heard from the adjacent street.

The measurement location was chosen in the center of the room, where the microphone was away from the walls for more than 1 m, at a height of about 1.2 m from the floor.

### 4.2.2. The measurement of vibration

In order to evaluate vibration in the building with respect to comfort, the overall $W_m$-frequency weighted values of r.m.s. accelerations and $VDV$ were measured, as prescribed in [4]. The following equipment, shown in Fig. 6, was used for the measurement of vibration signals:

- Human Vibration Analyzer, type 4447, and
- triaxial accelerometer, type 4506, by Bruel&Kjaer.

The Human Vibration Analyzer Type 4447 complies with the technical requirements of ISO 8041:2005, Human response to vibration - Measuring instrumentation, and can perform measurement compliant with the standards pertaining to human vibration. The instrument is designed primarily for use in Health and Safety at Work applications. Along with the pre-set frequency weightings for hand-arm ($W_h$) and whole-body ($W_d$ and $W_k$) vibrations, it possesses the pre-set frequency weighting ($W_m$) for the measurement of building vibrations too. Triaxial accelerometer is the classical vibration sensor which delivers the measured signal to the analyzer for further processing.

The measurement of the r.m.s and $VDV$ values of the frequency weighted acceleration was done over period of 1 h, for the cases when machine installations were on and off. The accelerometer was mounted on the floor using double adhesive tape, and measurement was done for several variation of the accelerometer position.

*Figure 6. Human Vibration Analyzer type 4447 by Bruel&Kjaer and triaxial accelerometer*

### 4.3. RESULTS AND DISCUSSION

The measurement results of the r.m.s. and the $VDV$ values of acceleration are given in Table 5. Referring to the values as shown in Table 1 and 2, one can conclude:

- for the case when the machine installation in the office was off, the r.m.s. values are just slightly above the threshold of perception (0.015 $m/s^2$), while the $VDV$ value for the time interval of 8 h points to "low probability of adverse comment".
- for the case when the machine installation in the office was on, the r.m.s. values point to "low probability of adverse comment" for the exposure period of 8 h, while the $VDV$ value for the time interval of 8 h points to "adverse comment possible".

Table 5. *Measured r.m.s. ($m/s^2$) and $VDV$ ($m/s^{1.75}$) values of acceleration*

| Conditions | r.m.s. ($m/s^2$) 8h | $VDV$ ($m/s^{1.75}$) 8h |
|---|---|---|
| the machine installation in the office was off | 0.0174 | 0.273 |
| the machine installation in the office was on | 0.039 | 0.730 |

The measurement of the equivalent noise level was performed during daytime and night-time, and measurement results are given in Table 6. The graphic representation of the measured sound levels for daytime and night-time are presented in Figures 7 and 8.

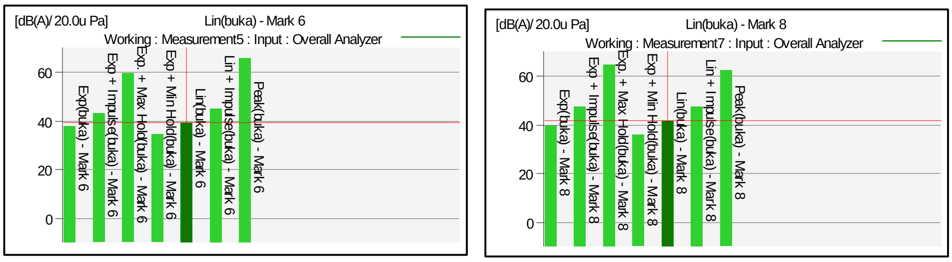


*Figure 7. Sound levels for daytime: a) $L_{Aeq}$ = 38.7 dB (the machine installation in the office was on), b) $L_{Aeq}$ = 41.2 dB (the machine installation in the office was off)*

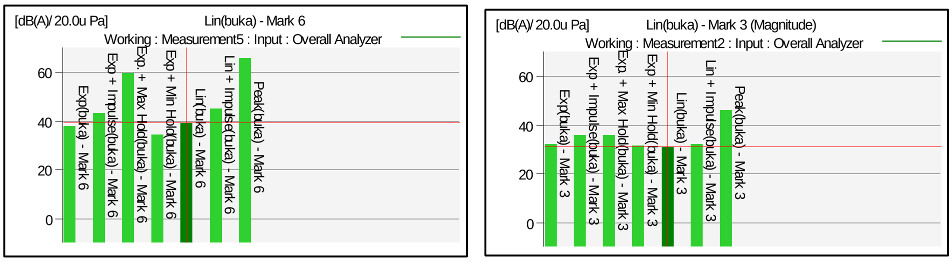


*Figure 8. Sound levels for night-time: a) $L_{Aeq}$ = 35.7 dB (the machine installation in the office was off, household appliances – the refrigerator was on), b) $L_{Aeq}$ = 30.8 dB (the machine installations in the office was off; household appliances – the refrigerator was off)*

Table 6. *Measured A-weighted equivalent continuous sound pressure level*

| | Time and day | Sound level $L_{Aeq}$ (dB) | Note |
|---|---|---|---|
| Daytime period | 9:15 - 9:30 Saturday | 36.9 | not known whether the machine installation in the office was on or off |
| | 14:45 - 15:00 Tuesday | 38.7 | the machine installation in the office was on |
| | 15:30 - 16:00 Tuesday | 41.2 | the machine installation in the office was off |
| Night-time period | 21:45 – 22:00 Friday | 35.7 | household appliances /refrigerator/ was on; the machine installation in the office was off |
| | 22:00 -22:15 Friday | 30.8 | household appliances /refrigerator/ was off; the machine installations in the office was off |

In accordance with the prescribed permissible noise levels as shown in Table 3, the measured noise is estimated as follows:

- The equivalent noise level $L_{Aeq}$ = 36.9 dB measured at the time interval 9:15 - 9:30 hrs doesn't exceed the permissible level of $L_{Aeq}$ = 40 dB for daytime.

- The equivalent noise level $L_{Aeq}$ = 38.7 dB measured at the time interval 14:45 - 15:00 hrs, when the machine installation was on, doesn't exceed the permissible level. The equivalent noise level $L_{Aeq}$ = 41.2 dB, measured at the time interval 15:30 - 16:00 hrs when the machine installation was off, exceeds the permissible level of $L_{Aeq}$ = 40 dB, if the assessment criterion is the permissible level of noise emitted from the source inside the building (criterion A in Table 3). However, this measurement was performed during busy hours, and it was concluded that higher traffic volume raised the noise level for 2.5 dB, although the machine installation was off. Since the traffic is a non-stationary source outside the building, the assessment criterion should be the permissible level of noise emitted from the source outside the building (criterion B in Table 3), and according to this criterion, the permissible level of $L_{Aeq}$= 45 dB for daytime is not exceeded.
- The equivalent noise level $L_{Aeq}$= 35.7 dB measured at the time interval 22:00 - 22:15 hrs exceeds the permissible level of $L_{Aeq}$= 30 dB for nigh-time. The refrigerator placed in the room was on during noise measurement. After the refrigerator was turned off, the equivalent noise level of $L_{Aeq}$= 30.8 dB was measured. Taking into account the traffic noise which was heard during measurement, the permissible level of noise emitted from the source outside the building (criterion B in Table 3) was chosen as the assessment criterion, and according to this criterion there is no exceedance of the permissible level of $L_{Aeq}$= 35 dB for night-time

Although the results of the objective noise measurement showed no exceedance of the permissible noise levels, it was found that the requirements of architectural acoustics were not fully met during reconstruction of the ceiling in the office rooms below the apartment. Specifically, the mechanical installations of the ventilation and air conditioning systems in the office were placed within the area of the lowered ceilings that border the apartment. Thus, an acoustic standard has not been met, according to which it is desirable to avoid direct contact of noisy rooms and noise-sensitive rooms. This is especially significant for the analyzed case, because the analyzed apartment is a one-room studio, so it falls under the category of rooms particularly sensitive to noise.

It was found that the ventilator was installed inside the ventilation duct in the lowered ceiling of the ground floor. The ventilator was mounted laterally to the structural AB beam, but no elastic support elements for the ventilator and pipe were used. The pipe outlet is located in the wall under the windows of the apartment. Installation of ventilation system is primarily the problem of airborne noise in buildings that are radiated into the rooms through the ventilation outlets or the airborne noise emitted by ducts made of tin-plated walls into their environment. Ventilation duct might in some cases create structural-borne noise in the building structure through hanging or support points.

## 5. CONCLUSIONS

Human response to vibration in buildings is very complex. The analyzed case shows that other parameters related to vibration sources inside and outside buildings, or produced by vibration in exposure area such as structure-borne and airborne noise, may also give an explanation of the complaints. In the analyzed case of adverse comment to noise and vibration in residential building, it was shown that the requirements of architectural acoustics were not fully met. During reconstruction in the office rooms below the apartment, the mechanical installations of the ventilation and air-conditioning systems were set improperly into the lowered ceiling, producing annoying noise and vibration. Although the results of the objective noise measurement didn't show any exceedance of the permissible noise levels, it is recommended that the duct be mounted by using elastic elements.

In the acoustic practice, there are different ways to reduce the impact of noise emitted by the mechanical installations in buildings. The most important measure is to carefully make the plan of the internal organization of the installation facility at the very beginning, i.e. in the development phase of the project. It is particularly important to minimize the setting of installation next to rooms that are critical from the aspect of sound protection (e.g. bedrooms), as this measure is cheaper than any subsequent solution offered by acoustics.

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