Indoor Noise Loading in Residential Prefabricated Buildings

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Abstract. Quality on indoor environment is among others also defined by an acoustic comfort and noise emissions. The indoor noise loading in the residential prefabricated buildings is specific problem related to structural design of these buildings. Problems with noise level of sanitary systems are mostly associated with hydraulic shock such as water distribution and sewage drainage. Another very common cause of excessive noise is also flushing the toilet or water fall on enamelled steel (bath or shower). This paper aims to analyse the acoustic properties in the residential prefabricated buildings. Sanitary core of the assessed apartment is in original condition without any alterations. The sanitary core is based on a formica (high-pressure laminate). The study discusses the maximum sound levels in the three assessed rooms for the three different noise sources. The values of maximum noise level are measured for the corridor, bedroom and living room. Sources of noise are common activities relating to the operation of sanitary core - the toilet flush in the toilet, falling water from the shower in the bathroom and the water falling on the bottom of the kitchen sink in the kitchen. Other sources of noise are eliminated or minimized during the experiment. The digital sound level meter Testo 815 is used for measurements. The measured values of maximum sound level \( L_{A,\text{max}} \) [dB] are adjusted by the correction coefficient. The obtained values are compared with the hygienic limits for day and night period. Night hygienic limit (30 dB) is exceeded in all the rooms for all noise sources. This limit is exceeded from 17 to 73%. The values in the bedroom and the living room meet the daily hygienic limit (40 dB). The daily limit is exceeded only in the corridor. The highest values of noise are identified for the toilet flushing.

1. Introduction
Acoustic comfort is one of the basic prerequisites for a quality indoor environment. The sound is an integral part of each individual's life. It is necessary to distinguish between sound and noise. People are constantly exposed to vibration, shock and noise. The sound is a sensory perception of sound waves. Noise is defined as unwanted and intrusive sound. Frequent and excessive noise are among the significant stressors. Increased level of unpleasant noise negatively affects the quality of the indoor environment [1]. Noise is often a nuisance, and is sometimes a genuine danger to human health and safety. The adverse impact of noise on indoor environment can be also significant. Indoor noise needs to be assessed with respect to risk for both human health and wellbeing. Excessive noise is one of causes of the Sick Building Syndrome (SBS). There are a number of studies on the effects of excessive noise on performance, comfort and human health [2-4]. Over limit noise pollution causes internal tensions and imbalances of the body. Exposure to excessive noise can cause insomnia, headaches, sickness, stomach ulcers, high blood pressure, increased irritability and even impotence [5, 6]. The negative effects of noise exposure are not reflected immediately, but in the long term. There are also several problems...
associated with the assessment of perceived noise exposure over a period of time. During each day, a person is exposed to a variety of environmental noises at home, in the general environment and at work. This pattern might change from day to day or year to year. The perceived noise exposure is changed with age, lifestyle, occupation and many other factors. Special regard must be paid to the so-called sensitive groups as these may react negatively to a lower sound pressure level of noise than others. It can be explained that the majority of user’s complaints were from the older dwellers. Thus estimates of total noise exposure are always very crude approximations. The effectiveness of building structures for noise control is very important. Any part of a building which is interposed between a noise source and a sensitive receiver will reduce some amount of transmitted sound energy. It is often important to be able to specify the amount of sound reduction that can normally be expected from different types of construction for design purposes. There is no point in specifying construction acoustic properties rating between two rooms if there is a flanking path via with a low sound reduction rating [7].

2. Residential prefabricated buildings and sanitary cores
Almost all European countries are faced with a lack of housing after the end of the 2nd World War. The main task of the construction industry was the restoration of the housing stock. The construction prefabricated panel houses appeared to be the ideal solution. The speed of construction, installation in the winter, fast construction and enough building materials (silicates) decided to the massive development of prefabricate constructions in the Czech Republic [8].

Currently, the panel housing estates surround the downtown of all major cities in the Czech Republic. These housing estates create a substantial part of the housing stock of the Czech Republic. More than 54% of apartments in the Czech Republic is located in prefabricated panel buildings. It is registered more than 3.7 million residential units. The share of residential units in apartment buildings is approximately 40%. There are a variety of construction systems of prefabricated houses. Attention is primarily devoted to the regeneration of these buildings in terms of thermal and technical properties. The majority of prefabricated panel houses in the Czech Republic are multi-story apartment buildings based on reinforced concrete. Frequent complaints about excessive noise from neighbours are typical for these objects. The noise sources in the prefabricated panel buildings include the heating, ventilation and air conditioning (HVAC), dog barking, children’s running and jumping, voices, hammering, falling items and next [9].

The biggest weakness of prefabricated panel houses is the sanitary core. The sanitary core is an essential element of the overall layout of the apartment or house. The position of the sanitary core is always linked to the HVAC installations. The installation shaft connects the apartment’s device on the vertical distribution of water, sewer and gas. Sanitary core resolves connection toilet, bathroom and kitchen in individual apartments of prefabricated houses. It also includes a ventilation pipe for exhaust air from the bathrooms, toilets and kitchen hoods. The development sanitary cores copies the development of the systems of prefabricated buildings. Numerous types of prefabricated houses was from 60th to 90th years of the last century. The individual types of sanitary core are different in terms of various technologies in the distribution of technical installations and their implementation. The advantage of sanitary cores is their prefabrication and following fast construction.

There are two basic types of sanitary cores in term of building material - reinforced concrete or formica. More than 90% of the sanitary cores in prefabricated panel buildings is based on a formica. Sanitary cores based on Formica (Czech known as umacart) is typical sandwich construction. Production of Czech Formica was terminated in 2004. The skeleton of core is made of wood (usually spruce prisms). Skeleton core usually contains aluminum conductors. The frame is filled with expanded polystyrene. Polystyrene is covered by formica - paper hardened with synthetic resin. Formica is a kind of high-pressure laminate (HPL). Formica is highly resistant to abrasion and chemicals. Formica has an impermeable surface. It is hygienic and easy to clean. Another advantage is durability. The great disadvantage is low (almost zero) load capacity. Ordinary thickness of the formica core is 30 mm. Equipment items should be anchored to the frame construction of sanitary cores. Another problem is the frequent occurrence of putrefaction and mold due to the high humidity.
3. Experimental measurements

The experimental study were carried out in the typical apartment in the residential prefabricated building located in Poruba, district of the city of Ostrava, Moravian-Silesian Region in the Czech Republic. The building has undergone revitalization (external thermal insulation composite systems and replacement of windows) 10 years ago (figure 2 on left side). The measured apartment is situated on the fourth floor at the central entrance of building. The figure 1 shows the scheme of floor plan of this apartment. The apartment consists of two rooms and a kitchen. Room 1 is used as a bedroom and room 2 is used as a living room. The central residential core with sanitary system consists of a bathroom, toilet and kitchen. The sanitary core is designed with separate entrances to the bathroom and toilet. Figure 2 right shows the original condition of the sanitary core. Total floor area of apartment is approximately 66 m². Headroom of the apartment is 2.6 m.

![Figure 1. Scheme of floor plan of the apartment](image)

The measurement is carried out under original construction condition (without alterations and renovations). Three indoor sources of obtrusive noise are evaluated. The values of maximum sound level $L_{A,max}$ [dB] are measured for sources from bathroom, toilet and kitchen for reference frequency 1000 Hz. The indoor maximum sound levels are determined for corridor, room 1 and room 2 at 8:00 pm. The measurement is carried out in accordance with the ISO 1996-1 (2016) [9]. The digital sound level meter Testo 815 is used for measurements. The measuring device is placed in the middle of the tested room. The digital sound level meter is at the height of 1500 mm from the floor.
Figure 2. View of the front façade examined prefabricated panel house (left) and view of the installation formica core of tested apartment (right)

Typical activities of using apartment sanitary core are sources of noise. The effect of flushing the toilet is noise source in the toilet room. The ceramic flushing cistern with the volume of 10 litres is freely in space above the toilet bowl. The maximal water flow from shower head falling to the bottom of the tub is the second noise source. The height of the shower head and the bottom of the tub is approximately 1500 mm. The last source of noise is situated in the kitchen. The maximal water flow falling to the bottom of the stainless kitchen sink is investigated. All other activities (for example cooking or cleaning) and operation of electrical appliances (computer, TV, radio, kitchen hood and next) are minimized during the measurement. All doors and windows are closed.

4. Results and discussions
The results of maximum noise levels in selected room in apartment for selected noise sources are shown in table 1. The measured values $L_{A_{\text{max}}}$ [dB] are corrected according to the Government Regulation No. 272/2011 on protection of health from adverse effects of noise and vibrations [11], in the current version No. 217/2016. The obtained values are compared with the actual hygienic limits. Hygienic limit for the maximum noise level is defined as a sum of noise sources inside the buildings. The limit of maximum noise level is determined on 40 dB for day period and 30 dB for night period. These limits are applicable to the protected interior space.

| Table 1. Results of maximum sound level in assessed rooms for selected noise sources |
|---------------------------------------------------------------|
| **Noise source** | **Maximum noise level** $L_{A_{\text{max}}}$ [dB] | **Corrected maximum noise level** $L_{A_{\text{max}},c}$ [dB] |
| Corridor          |                                              |                          |
| Kitchen           | 35                                           | 40                       |
| Bathroom          | 42                                           | 47                       |
| Toilet            | 47                                           | 52                       |
| Room 1            |                                              |                          |
| (Bedroom)         |                                              |                          |
| Kitchen           | 35                                           | 40                       |
| Bathroom          | 30                                           | 35                       |
| Toilet            | 30                                           | 35                       |
| Room 2            |                                              |                          |
| (Living room)     |                                              |                          |
| Kitchen           | 30                                           | 35                       |
| Bathroom          | 30                                           | 35                       |
| Toilet            | 32                                           | 37                       |

All of the measured sites exceeded the hygienic threshold $L_{A_{\text{max}},c}$ during the night. The highest values of maximum sound level are obtained for the corridor. The obtained values in the corridor exceed
standard limit for day period (40 dB) and for also night period (30 dB). The toilet flush causes exceeding the daily limit of 30% and the nightly limit of 73%. In case the shower as a noise source, hygienic limits are exceeded by 18% for the day and about 57% for the night. The source of the noise in the kitchen meets the threshold level for the time of day. Night hygienic limit is overrun by the 33%. Daily hygienic limits of maximum sound level for the bedroom (Room 1) are fulfilled. Night limit is exceeded most for the source of noise in the kitchen (33%). Flushing the toilets or flowing water from the shower exceeds the limit of 17%. Living room (Room 2) reaches the most acceptable values. The reason is the largest distance from the noise sources. Daily hygiene limits are complied with for all noise sources. Night hygienic limits are exceeded by 17% for kitchen and bathroom and by 24% in the case of the toilet as a noise source. Figure 3 graphically represents the results obtained.

![Figure 3. Results of maximum sound level in assessed rooms for selected noise sources](image)

**5. Conclusions**
Prefabricated panel constructions in different structural arrangement has the irreplaceable role in housing construction in the countries of Central Europe. Noise exposure is strongly related with the welfare and health of residents of prefabricated panel buildings. The most common sources of noise emissions in prefabricated buildings are ventilation systems, passenger elevators, heating system, water pipes and sewerage systems. A common noise sources are themselves residents and pets. The main problem of prefabricated panel buildings is the lack of acoustic insulation between the apartments due to the small thickness of walls. It is necessary to pay attention to the quality of the indoor environment in term of excessive noise during the regeneration of prefabricated panel houses. A suitable solution is replacement of original noisy sanitary equipment for modern systems in combination with acoustic insulation of walls, floors and ceilings.

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