The effects of thermal insulation on the interior noise level during the day. A case study of a 1960 block of flats located in downtown Bucharest

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Abstract. The issues related to the propagation of outside noise to the occupied spaces are more frequent, especially in urban areas where different types of noises are present (constructions, traffic, etc.). It is medically proven that noise has negative effects on health: anxiety, lower intellectual performances, stress, fatigue or higher blood pressure. With the national refurbishment program of old buildings the constructors are insulating and replace old wood frame windows with more energy efficient ones. Despite the clear benefits in terms of energy reduction there are still some questions about the sound insulation of the facades. If the windows replacement is done in a wrong way the situation can be aggravated as air and noise can overpass. In this paper using experimental measurements it is evaluated the impact of thermal refurbishment of an apartment on the acoustic comfort. The data showed that the windows represent the weak part of the facade and incorrect mounting severely affected the indoor sound pressure level.

1. Introduction

As a result of the adoption of a national strategy, in accordance with the policies of EU Member States on energy efficiency [1], Romania is one of the EU countries undergoing an intensive process of thermal rehabilitation. The process is mainly directed to the fund of old buildings from 1945-1989 (i.e. the communist era). These buildings are characterized by a very low level of energy efficiency. The rehabilitation started a few years after Romania's accession to the European Union in 2007. It involved the commitment to comply with the European energy efficiency directives which had several objectives, on the one hand a decrease in energy consumption and a reduction in the greenhouse effect, and on the other hand, a change in the mentality of citizens from EU member states, encouraging them to conserve and improve the quality of old buildings.

Unfortunately, these recommendations for energy saving were not accompanied by provisions related to acoustic comfort and the implementation of concrete measures to reduce the noise level in the buildings to be renovated. It has been assumed that thermal rehabilitation will automatically mean a reduction of noise, especially those from sources outside the buildings as well as increased acoustic comfort. However, this assumption was not sufficiently examined.

The purpose of this article is to criticize this point of view and to argue, with arguments based on empirical evidence, that thermal rehabilitation may be accompanied by a decrease in the sound performance of old residential buildings.
Recently, the Bucharest branch of the Romanian Order of Architects, published a report titled "The report for Bucharest 2016" [2]. According to the authors of this report, there are two types of buildings that need rehabilitation. The first type comprises the historical fund built up to 1940 which includes houses, villas, inter-war blocks, and the second type includes collective housing buildings from the communist and post-communist period. Each category involves different intervention solutions, which "depend on the value criteria and the building systems of the buildings" [3]. The report recalls some of the problems that rehabilitation with composite materials, such as expanded polystyrene and cheap PVC joinery for windows, raises from an aesthetic and functional perspective [3]. As far as can be noticed, nothing is said about measuring the unwanted acoustic effects of thermal rehabilitation under the conditions in which the city of Bucharest has been listed in the Eurostat report (2016) with the lowest level of population satisfaction regarding air quality (22%) and noise level (31%) from the total of 83 cities studied [4].

Also, an analysis of the online press, from 2009-2019, shows a complete lack of concerns regarding the acoustic performance of buildings that have been thermally rehabilitated and, even less, for their acoustic rehabilitation. This finding indicates that the problem was not brought to the public's attention either by architects, or by builders, or by other specialists. It is a good opportunity to change this state of affairs.

As mentioned earlier, the assumption from which the Romanian experts start, in the analyzed documents, is that the thermal insulation of the housing blocks is constantly accompanied by an increase of the acoustic performance of the individual houses. Recent research, however, shows that thermal insulation with composite materials called External Thermal Insulation Composite System (ETICS) can lead to either an increase or a maintenance of the level or a decrease of the acoustic performance of the houses [5]; [6]; [7]. The effects depend, as shown by L. Weber et al. from the Fraunhofer Institute of Building Physics (IBP), Stuttgart, of the wall structure and thickness on which it is intervened by applying thermal insulation [5]. The same conclusions are reached by K. Miskinis et al. in their experimental study [8]. In the case of the thermal rehabilitation of the old buildings, erected between 1960-1980, the studies indicate rather a decrease of the overall acoustic performance of the buildings. The sound insulation obtained by the rehabilitation of the old buildings also depends on the degree of transparency of the walls and windows, and for certain levels of ambient noise, the insulation proves to be ineffective [9]. As EU policies continue to intensify the process of thermal rehabilitation, without considering the potentially negative effects of some types of thermal insulation on a housing stock with low initial acoustic performance, the specialists insist on the need to adopt thermal solutions, optimum acoustics, by adding an acoustic rehabilitation process to the thermal rehabilitation process [6]; [10]. There is even a discussion of a concept of "free dB" regarding the rehabilitation of the old European real estate fund [10].

It is therefore necessary to evaluate the impact that the thermal rehabilitation has on the acoustic performances of the houses undergoing the rehabilitation process. Why? If the level of acoustic performance of the old blocks, thermally rehabilitated, is low, as shown by studies performed in other countries, with values falling below the thresholds recommended by national and international standards, this can lead to the generation of a major public health problem through acoustic stress [11]; [12]; [13]; [14]; [15]; [16] induced by insufficient sound insulation of individual dwellings. Under these conditions, acoustic control measures are required [17], through a national acoustic rehabilitation program for this category of dwellings, in line with EU and WHO recommendations in this direction [18]; [19]; [20].

The general topic of this paper is urban noise pollution and the way the current thermal rehabilitation program, embraced by all EU countries in the last 40 years, contributes to its amplification at the interior of urban dwellings. Specifically, in this paper we will refer to the noise level during daytime caused by exposure to urban noise generated inside those buildings subject to thermal rehabilitation with composite materials of the ETICS type, in the capital city of Romania.

The questions to which this study aimed to answer can be formulated as follows: is thermal insulation accompanied by an acoustic insulation of the blocks rehabilitated with ETICS composite material?
Does the level of interior noise in urban dwellings during the day fall within the limits recommended by the World Health Organization (WHO)?

In order to test a façade airborne noise, we refer mainly to ISO standards [21] that precise the exact steps for the determination, "in situ," of a façade sound attenuation index. Experimental measurements of different residential buildings are also found in the article published by Hoffmeyer and Jakobsen [22][23], Møller and Pedersen [4] or that analyzed the sound propagation even at low frequencies (<50 Hz). WHO recommendations are mostly related to the level of nighttime noise that impacts on the quality of sleep and indirectly to an effect on the health of those exposed to environmental noise in urban areas. However, daytime acoustic comfort is also of high importance. Within this article multiple experimental measurements were conducted in order to calculate the sound transmission index of a new refurbished block of flats. The measurements were realized during daytime in a two-room apartment.

2. Case study

The apartment that is the subject of this case study is located on the 5th floor of a 6-storey building. The block of flats is located on the corner, at the intersection of two secondary streets, from the sector 1 of Bucharest, near the Cişmigiu Park. The block has a horizontal section in the form of a trapezium, the large base being joined to the blind wall with another block, and the small base being directed towards a square with a four-way opening. The apartment consists of two rooms, a kitchen, a vestibule, a bathroom, a hall and two loggias. The first loggia is located on the façade facing the square, and the second one is facing one of the sidewalks, being attached to the kitchen. Compared to the original plan, the apartment underwent several alterations, in the sense that the kitchen door was dismantled, the loggia was incorporated into the kitchen, the storage closet was dismantled, being also incorporated into the kitchen in order to enlarge it sufficiently. The windows of the kitchen loggia, the bedroom and the living room were replaced with PVC windows with multilayered wood frames. The bedroom wall facing the square is made up of windows and a large sliding door with double glazing windows. The entrance door opens in a long corridor. On the hall, joining the two large corridors, there are the doors of the two lifts serving the block. The areas of each room are: living room (22.66 m²), bedroom (16.77 m²), kitchen (4.13 m²), bathroom (3.12 m²), vestibule (5.98 m²), hall (0.90 m²) living room (4.72 m²), bedroom loggia (5.45 m²). The total area of the apartment is 65.79 m². The block was put into use in the year 1960 and has it brick walls and a reinforced concrete structure.

Figure 1. Plan and photo of the studied apartment
3. Method

The experiment was performed during daytime in March 2019. The measurements were performed in three locations inside the apartment: one in the bedroom (the orientation was towards the Iosif Sava Square - NW), the second in the living room, in the corner of building, and the third measurement in the kitchen. For the 3 rooms the acoustic measurements were performed in order to determine the reverberation time and to calculate the acoustic level inside the apartment and the acoustic level outside the apartment, next to each room [21]. In order to measure the indoor acoustic sound level (SPL), the sonometer was placed at 2 meters from the chamber wall, and the same was done for the measurement of the external acoustic level, but in this case the sonometer was set about 2 meters from the façade, outside the building. Using an artificial noise source, it was possible to simulate a sound field. The position of the artificial sound source and the distance to the façade were chosen so we could minimize the variation of the SPL. The distance from the artificial sound source to the tested facades was higher than 5m and the sound incidence angle was (45±5)°. The SPL was measured by frequency using a SVANTEK Soundmeter Class 1 Precision. A mandatory step during the experimental field trip was to measure the background noise levels. The receiving rooms were not affected by any indoor noises and the background level was at least 6 dB below the level of the signal and background noise combined.

4. Results

The measurements were realized for different frequencies. The global A-weighted sound pressure level was also calculated based on the measurements.

![Figure 2. Experimental results on sound pressure level for the facade 1](image)

It can be observed from Figure 2 that during the measurements the global sound pressure level is slightly fluctuating with an average value of 75.2 dB(A). The lowest values were obtained for higher frequencies. As concerns the indoor noise pressure level we found higher variations for f=1000 Hz but as for the global pressure this was averaged to 51.1 dB(A). The difference is low and clearly points out that the facade does not correctly sound proof the indoor space. For this facade the leaking paths are represented by the window and door frame.
As concerns the second room the situation is much better as the difference between outdoor noise and indoor is more than 42 dB(A). It is a clear evidence that for this specific facade the transmission loss is much higher, and the thermal refurbishment was better executed.

The target acoustic levels in buildings are important and for example, in living rooms, the A-weighted noise level should not exceed 30 dB in the daytime. This concerns both domestic noise from neighborhood and environmental noise. In our case, this limit was exceeded but, it must be specified that, at the same time, the outdoor noise level had excessive values. The reverberation time was measured in all three tested rooms and due to the fact that the apartment furniture was heavy with curtains, carpets, etc. the sound absorption area was very high. The reverberation time (RT) is characterized by the length of time needed for the noise level of a sound to drop by 60dB after the cessation of the emission by the source. In our case the RT had very low values, around 0.3 sec for almost all frequencies.

Sound reduction index, SRI is the most usual product-related acoustical quantity. The sound reduction index, SRI, is defined by:

$$ R = 10 \log \frac{1}{\tau} = 10 \log \frac{W_1}{W_2} \text{ dB} \quad (1) $$

where $\tau$ is the transmission coefficient, and $W_1$ and $W_2$ (W) are the incident and transmitted sound powers, respectively. The incident sound power can be determined by the average sound pressure, $p_1$, (Pa) of the source room in the steady-state situation.

$$ W_1 = \frac{p_1^2}{4\rho_0 c_0} S \quad (2) $$

where $S$ (m$^2$) is the area of the test specimen, $\rho_0$ (kg/m$^3$) is the density of air and $c_0$ (m/s) is the speed of sound in air. The transmitted sound power is determined, accordingly, in the steady-state situation, when the sound power radiated by the specimen equals the absorbed sound power in the receiving room:

$$ W_2 = \frac{p_2^2}{4\rho_0 c_0} A_2 \quad (3) $$

$$ A_2 \approx 0.161 V_2/T_2 \quad (4) $$

where $p_2$ is the average SPL in the receiving room, and $A_2$ (m$^2$) is the room absorption area of the receiving room. The volume of the room and the reverberation time are $V_2$ and respectively $T_2$. From the equations (1) to (4) the SRI can be calculated as follows:

![Figure 3. Experimental results on sound pressure level for the facade 2](image-url)
\[ R = L_{p1} - L_{p2} + 10 \log \frac{S}{A^2} (dB) \]  

where \( L_{p1} \) and \( L_{p2} \) are the average sound pressure levels in the source and receiving room, respectively. For cases where an artificial loudspeaker is used the sound insulation is investigated as function of the angle of incidence. The sound Reduction Index, \( R_\theta \) is calculated for the angle of incidence, \( \theta \) as follows:

\[ R = L_{p1} - L_{p2} + 10 \log \frac{4S \cos \theta}{A^2} (dB) \]

And for an angle of incidence of 45° we have:

\[ R = L_{p1} - L_{p2} + 10 \log \frac{S}{A^2} - 1.5 (dB) \]

In dwelling houses, the sound reduction index (SRI) should be at least 55 dB. For the studied case the calculations showed a poor SRI for the bedroom. The data are presented in Table 1.

**Table 1. Sound attenuation index of the facades 1, 2 and 3**

| Frequency |
|-----------|
| 125 | 250 | 500 | 1000 | 2000 | 4000 |
|----------|
| R_gl_Exp | 16.2 | 16.0 | 13.5 | 12.5 | 23.9 | 23.5 |
| R_gl_Teo | 30.3 | 29.3 | 29.4 | 36.4 | 43.4 | 39.4 |
| Difference (dB) | 14.1 | 13.4 | 15.9 | 23.9 | 19.5 | 16.1 |
| Difference (%) | 47% | 46% | 54% | 66% | 45% | 41% |
| Rw.th | 27.0 | 26.0 | 26.0 | 33.0 | 40.0 | 39.0 |
| Rw.exp | 12.8 | 12.6 | 10.1 | 9.1 | 20.5 | 19.9 |

It can be seen on the table above and on the chart the difference of the sound attenuation index between windows in the kitchen and living room comparing to those in the bedroom where there is a serious noise pollution especially in the bedroom – due to poor the window joints. The windows were found to be weak points of the thermal rehabilitation. Poor installation lead to severe noise pollution. Also, in kitchen and living room the sound attenuation index it is more closely to those measured and determined in the literature with maximum errors of 15%.
5. Conclusions

In the last decade, Romania has carried out an intensive program for the rehabilitation of the building fund from 1945-1989 in order to increase their energy performance. One of the positions held by the experts involved in this process is that the thermal rehabilitation also leads to an increase in the acoustic performance of the old houses.

The case study presented here aimed to examine this position and determine whether it can be supported by empirical evidence. For this purpose, a block of flats was chosen which was built in 1960, located in the center of Bucharest near the old Cișmigiu park.

Data from the recently published literature on this topic have been examined in order to understand the effects of thermal insulation on the acoustic performance of old homes. The data resulted from measurements made both in the laboratory and in situ indicated that, with the appropriate thermal refurbishment of buildings, the facades are also improved in terms of sound proofing. However, there are cases where low quality installation of windows can drastically reduce the sound reduction index.

The glass and the frame represent the main component that determines the acoustic insulation of the entire window.

The results of this study indicated that, for the examined case, an old apartment, recently thermally insulated, exposed to a high level of noise during the day, the main noise pathway are the windows and the sliding door to the open balcony. Serious noise propagation was found especially in the bedroom – most probably due to poor window joints. The windows were found to be weakest points of the thermal rehabilitation. Poor installation led to severe noise pollution inside the apartment, with values that exceeded the WHO recommended level in some areas.

In our opinion, it is necessary for this line of research to be continued by larger teams of experts and, in this way, to carry out several field studies to map the entire old housing stock in Bucharest. These should be duplicated by laboratory studies that can lead to a more precise modeling of the effects that the addition of various types of thermal insulating materials exerts on the acoustic performance of the recently rehabilitated or undergoing thermal rehabilitation blocks. An important result of this mapping could be the adaptation of the thermal rehabilitation process to the low level of acoustic performance of the old dwellings, but also an awareness of the main stakeholders regarding the potentially harmful effects that an additional reduction of the acoustic comfort level has on the health status of the population in the urban area.

6. References

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