EUROREGIO BNAM2022
Joint Acoustics Conference
9th-11th of May, Aalborg, Denmark

Transformation of office space to laboratory listening room

Lukáš Zelem[1*], Vojtech Chmelík[1], Daniel Urbán[1] and Monika Rychtáriková[2,1]

[1] STU Bratislava, Faculty of Civil Engineering, Radlinského 11, 810 05 Bratislava, Slovakia

[2] KU Leuven, Department of Architecture - Campus Brussel and Gent, Hoogstraat 51, 9000 Gent/Paleizenstraat 65, B1030 Brussel, Belgium

*lukas.zelem@stuba.sk

Abstract
The issue of sustainability in society leads to efforts associated with changing the purpose of conventional spaces while maintaining the essence of the original building. Therefore, the change of use of the spaces is a common process during the buildings' life cycles. However, if the purpose of the room with lower requirements is transformed to a room with higher requirements, in terms of building physics, it is necessary to look at the given issue from multiple points of view. One of the basic points of view is to critically evaluate, whether there is a space in the building that has the potential to fulfil the requirements for a new purpose. This article is aimed at the transformation of the so-called office spaces to an acoustic laboratory designed for subjective laboratory listening tests. Within a given transformation, it was necessary to select a room, which eliminated possible sources of interfering sounds by its location. Subsequently, construction adjustments were necessary. These treatments were focused on the improvement of the building and room acoustics. The aim was to create a room with as low a background noise level as possible and high sound absorption at the same time. During the conversion process, we had to face several issues resulting from the original design of the space. Airborne sound insulation is improved using a gypsum board lining system. The sound attenuation of the newly designed listening room is ensured by materials with high sound absorption. Thanks to these adjustments, it was possible to significantly increase airborne sound insulation and reduce the average reverberation time. The laboratory is recently used for research as well as the teaching process.

Keywords: listening room, office, reverberation time, equivalent sound pressure level, sound insulation

1 Introduction

Nowadays trend of using unconventional spaces for a conventional purpose (or vice versa) has been enhanced by the pandemic of COVID-19 since the beginning of 2020 [1]. There has been a need for adaptation of rooms with large volumes to fulfil the requirements of local hygiene measures and sometimes even transformation of large atriums of schools into lecture halls or gymnasia into classrooms, etc [2]. The other consequence of pandemic can be seen in many administrative buildings that remained empty for a couple of months, after companies chosen to go for home office. Recently, retrofitting administrative buildings into dwellings became a very discussed topic [3-5]. Different (higher) requirements need to be fulfilled in dwellings in comparison with offices. Not all changes in space function are caused by a new release of hygienic requirements due to the COVID-19 pandemic. The need for room purpose changing could be also due to a need to create specialized space which is easily reachable from the office. In the following paper, the change of two offices into an acoustic laboratory dedicated for listening tests was done. During the process of conversion, we had to face several challenges, since the requirements on sound insulation as well as background noise levels for listening tests rooms are stricter in comparison with common office [6-8]. Standard for designing of listenig room for laboratory listening tests with loudspeakers exists [9].

The purpose of this case study was to create a laboratory space, well insulated from surrounding rooms, in order to obtain low background noise levels, and to treat the interior surfaces with sound absorbing materials, both necessary for the performance of high-quality laboratory listening tests. The laboratory consists of two parts, the mentioned listening room and adjacent control room where the noisy technical equipment, as well as operator of the listening test, are typically situated.

2 Analysis of potential sources of noise

The building-up of listening room was planned in the building of the Faculty of Civil Engineering at the Slovak University of Technology in Bratislava (STU SvF). The idea behind was to build a well-insulated acoustic laboratory which would be at the same time easily accessible for students of civil engineering and architecture (e.g. for presentation and demonstration purposes). The transformation of the original office space to a new purpose, required extended analysis of the potential indoor and outdoor noise sources (e.g. traffic, position of the elevator, activities performed inside the building, etc.), and detailed information about the building (e.g. type of structure, construction style and inspection of surrounding walls, floors and ceilings, etc.). Based on the mentioned information, the most suitable place in this multi-storey building was chosen. A scheme of the building and its orientation towards surrounding environment is shown in the Figure 1.

2.1 Exterior sound sources

The building is situated in the city center of Bratislava and thus close to a busy street (Radlinského) with a two-way tram line. The office space, chosen to be converted to the laboratory space, has been chosen at the 22nd floor (almost the highest floor in this building) in approximately 73 m above ground to reduce the levels of direct sound coming from the traffic. On the 23rd floor there are only storage places and silent infrastructure, which act as an extra buffer space between the roof and ceiling of the lab. On one hand, the traffic noise in front of the building façade is reduced by altitude but on the other hand the noise caused by unexpected wind impact on the building facades sometimes occurs.

2.2 Interior sound sources

The Figure 1 (in a green rectangle) shows a particular typological scheme of the 22nd floor of the Faculty of Civil Engineering. The black colour represents the positions of elevators, turquoise colour are classrooms and rooms with 3D printers. Red colour shows the position of designed listening room of the acoustic laboratory and blue colour is the control room of the acoustic laboratory. Grey colour shows corridors and public spaces. It is clear, that the highest acoustic load from interior sound sources will be caused by the movement of elevators, communication of students and moving of people down the hallway adjacent to the laboratory.

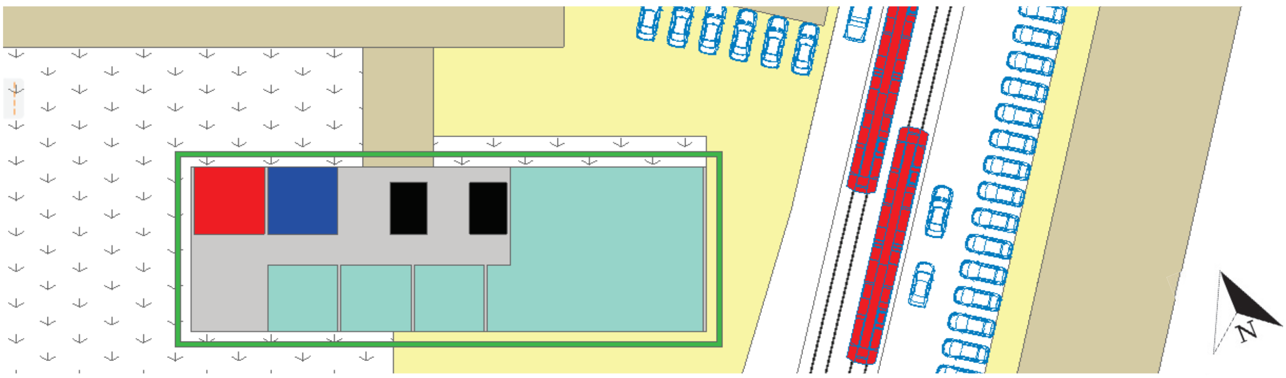

Figure 1 Schematic illustration of the STU SvF complex in Bratislava and the typology of 22nd floor in the high-rise building (the green rectangle) and its location related to the traffic.

3 Adaptation of the building constructions around the listening room

The basic structure of the building is based on reinforced concrete. The exterior walls are made out of autoclave concrete with thickness of approximately 300 mm. These walls ensure a high level of airborne insulation at low frequencies of the noise generated outdoors. Problem is a structure of a lightweight transparent façade from the north side of the building, which has a low mass and includes acoustic bridges. In addition, it is a subtle structure that is sensitive to wind impacts.

For this reason, an additional glazed wall (Glass Solutions), with increased acoustic properties, was built to improve the sound insulation of façade and to guarantee a day light in the listening room. The extra glazed wall creates a corridor, which thanks to its width increases airborne sound insulation at low frequencies too. The floor plan of the acoustic laboratory and its control room is shown in the Figure 2 left.

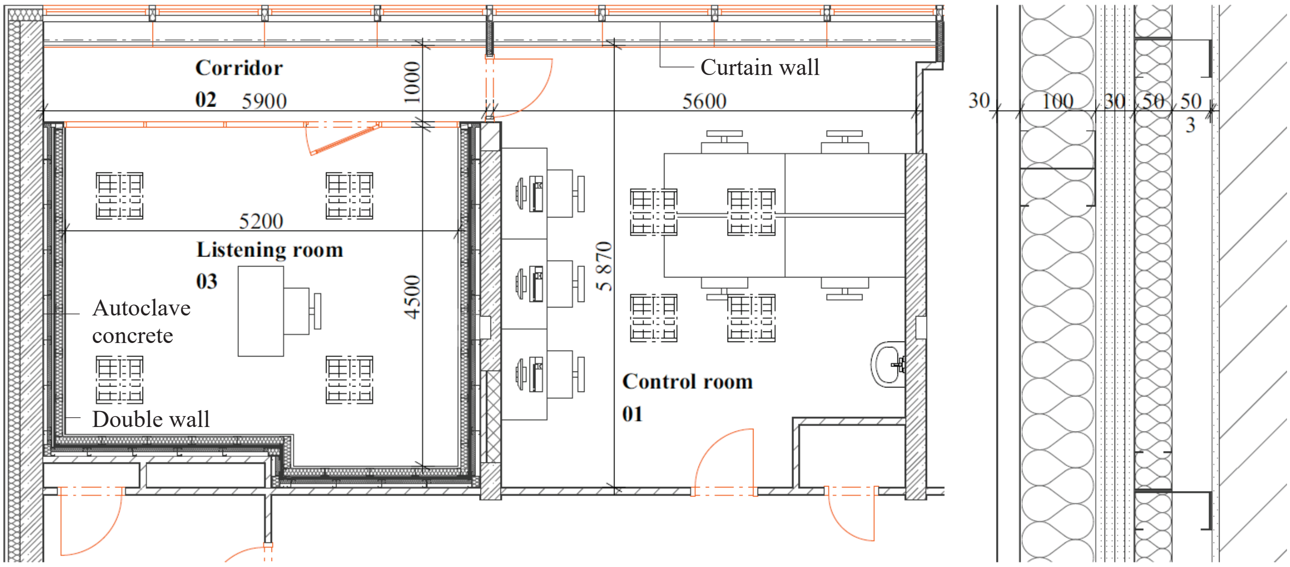

Figure 2 (Left) The floor plan of the acoustic laboratory - control room (01), corridor (02) and listening room (03). (Right) The composition of the additional lining of the wall in the listening room.

To increase the airborne sound insulation against interior sound sources, the double wall was designed. It consists of 4 layers of acoustic gypsum boards (Rigips ACTIV'AIR® MA AA - thickness of one board is 12.5 mm) built with distance of 100 mm from the original wall. The resulting air gap is filled with mineral wool (with thickness 50 mm). The frame for double wall is created from acoustic CW and UW steel profiles. Detailed composition of the listening room wall is shown in the Figure 2 (right). The whole frame is flexibly connected to the original structure to prevent transmission of vibration to plasterboards. Subsequently, the material with high sound absorption coefficient (mineral wool with thickness of 100 mm - Tab. 1) is placed on the whole wall surfaces, from interior side (except the glazed wall) using additional frame from steel profiles. Finishing of walls, i.e. covering of mineral wool is done by textile with high airflow coefficient to ensure the high absorption of the system. The ceiling is covered by acoustic Ecophon panels (Tab. 1) and floor is covered by carpet with thickness of 5 mm. It helps achieving the optimal room acoustic parameters in the listening room.

The above-described construction modifications, aimed at increasing of the airborne sound insulation in the considered listening room, don't solve problems with impact noise. Given relatively low height of ceiling, the impact noise insulation was solved especially typologically. Laboratory is located on the highest floor. Therefore, only the technical floor with minimum occurrence of persons is located above the listening room. Thanks to this, the impact noise from the floor above our protected room is not an issue. The second problem is the movement of the elevator in the elevator shaft and noises from the engine room of the elevator.

This noise source has been partially reduced by the positioning of the listening room at further distance from elevator. The same approach was applied for solving of the impact noise within one floor. Teaching rooms are in relation to the laboratory's positions as far as possible. If necessary, the classroom can be equipped with carpet as well as in the laboratory or control room.

Table 1 Sound absorption of materials used inside the listening room

Material	Product	Thickness (mm)	Frequency (Hz)						α_w (-)	Sound absorption class
			125	250	500	1 k	2 k	4 k		
Mineral wool panels	Isover Akuplat	100	0.55	1.00	1.00	1.00	1.00	1.00	1.00	A
Acoustic panels	Ecophon Master SQ	40	0.25	0.80	0.95	0.95	1.00	1.00	1.00	A

4 Objective assessment of acoustic adjustment

To determine the impact of acoustic treatments, the acoustically treated listening room was compared with the untreated control room. Both spaces were analysed in terms of sound insulation of walls and reverberation time. The background noise determined from equivalent sound pressure level measurements in the listening room compared with the control room too.

4.1 Room acoustic parameters

Room acoustics parameters were derived from impulse response measured by software Matlab - using ITA toolbox. The exponential sweep signal with a length of 5.46 s (5 repetitions) was used as excitation signal. Measurements were performed by means of omnidirectional loudspeaker and microphones Behringer ECM8000 with a flat frequency response from 20 Hz to 20 kHz. The impulse response was measured at 3 positions of sound sources and 6 positions of microphones in two heights - 1.2 and 1.8 above the floor and sound sources was placed at the height of 1.5 m above the floor (Fig. 3) (altogether 36 microphone positions). The measurements were performed according to the standard EN ISO 3382 - 2 [10] as "precision measurement" category (considering the number of measured sound sources and microphones positions).

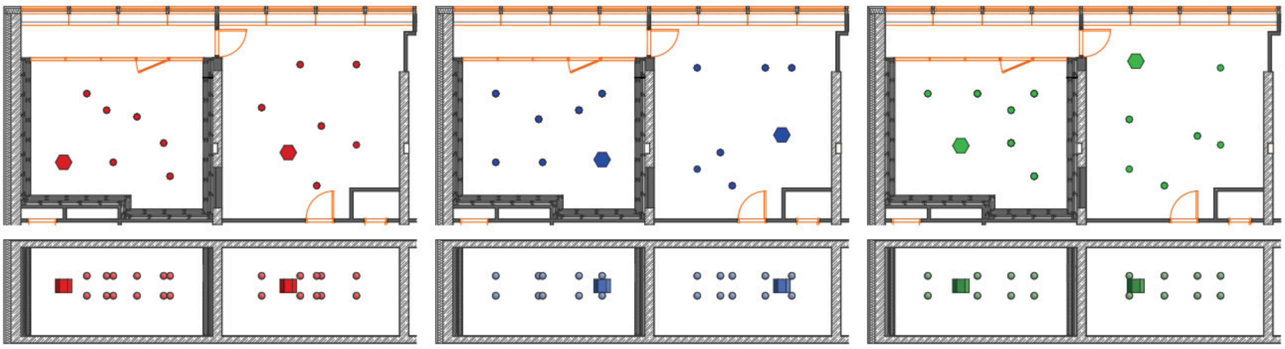

Figure 3 Floor plans (pictures above) and sections (pictures below) of sound sources positions (hexagons) and associated microphones (circles).

The values of early decay time *EDT* and reverberation time T_{10}, T_{20} and T_{30} for both rooms (listening room and control room) were derived from the impulse responses (Fig. 6). In the listening room, the course of the reverberation times and the *EDT* is almost identical (Fig. 4 left), in the control room the course of the *EDT* is different in the frequency spectrum from 1.6 kHz to 10 kHz (Fig. 4 centre). For comparison of the reverberation time of the two rooms, the T_{20} was chosen (Figure 4 - right). The reverberation time with indication of standard deviations in the control room is indicated by black triangles and the reverberation time in the listening room is shown in red circles. The effect of sound absorbing material in the listening room is very clear.

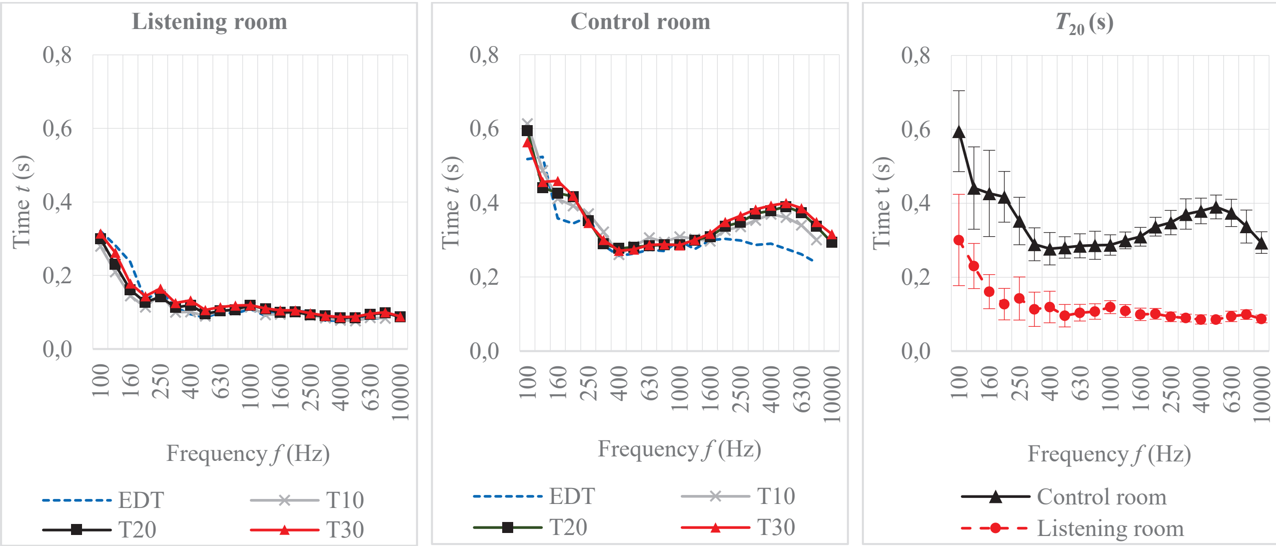

Figure 4 Comparison of *EDT* and reverberation time T_{10}, T_{20}, T_{30} in the listening room (left) and in the control room (middle) and the course of the reverberation time T_{20} with the standard deviation in the listening and control room (right).

4.2 Building acoustic parameters

Measurement was performed according to standard ISO 16283 - 1 [11]. The positions of microphones and sound sources are shown in Figure 7. The airborne sound insulation D_{nT} (standardized level difference) and D (level difference) values were derived from the measurements according to the procedure in the standard ISO 717 - 1 [12]. The pink noise signal in the frequency range from 20 to 20 kHz was generated by the omnidirectional sound source (Fig. 5 - right).

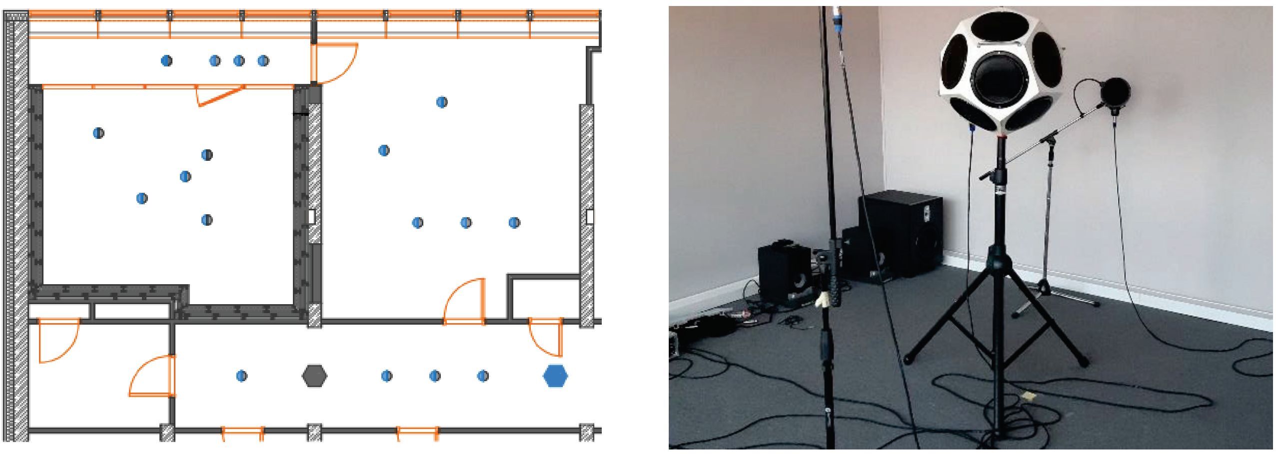

Figure 5 Positions of sound sources (hexagons) and associated microphones (circles) when measuring airborne sound insulation (left) and omnidirectional sound source (right).

Monitoring of sound pressure level was done by the Norsonic Nor140. The measurement of airborne sound insulation was made in the completely closed listening room. Further the door in the glazed wall was opened to investigate the influence of the glazed wall. The airborne sound insulation measurement between the control room and the corridor was realized only with completely closed door (Fig. 6). In Figure 6 on the left, we can see values of D_{nT}, both in the listening room and in the control room. The total $D_{nT,w}$ (weighted standardized level difference) value of the partition wall between corridor and listening room reaches 67 dB compared to the wall between corridor and control room, which reaches 33 dB. Thanks to the use of building modifications, an overall increase in airborne sound insulation $\Delta D_{nT,w}$ of 34 dB was achieved in case of listening room compared to the control room where original partition wall is built. In Figure 6 on the right, we can see the sound insulation between the corridor and the two rooms (listening room and control room) expressed in D values.

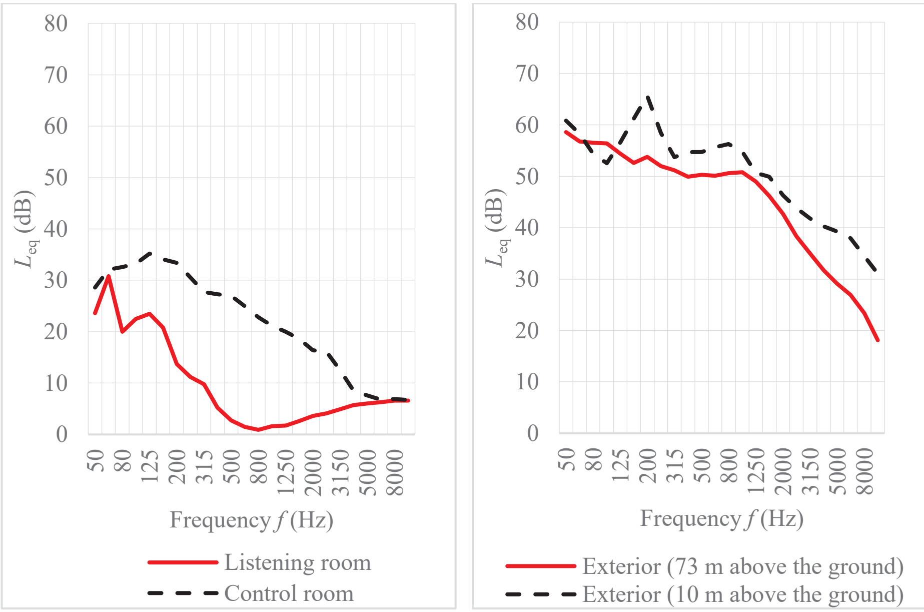

Figure 6 Equivalent sound pressure level L_{eq} in the listening room and control room in frequency domain. (left). Equivalent sound pressure level L_{eq} in the building exterior (2 m in front of fasade) at 2 different heights (right).

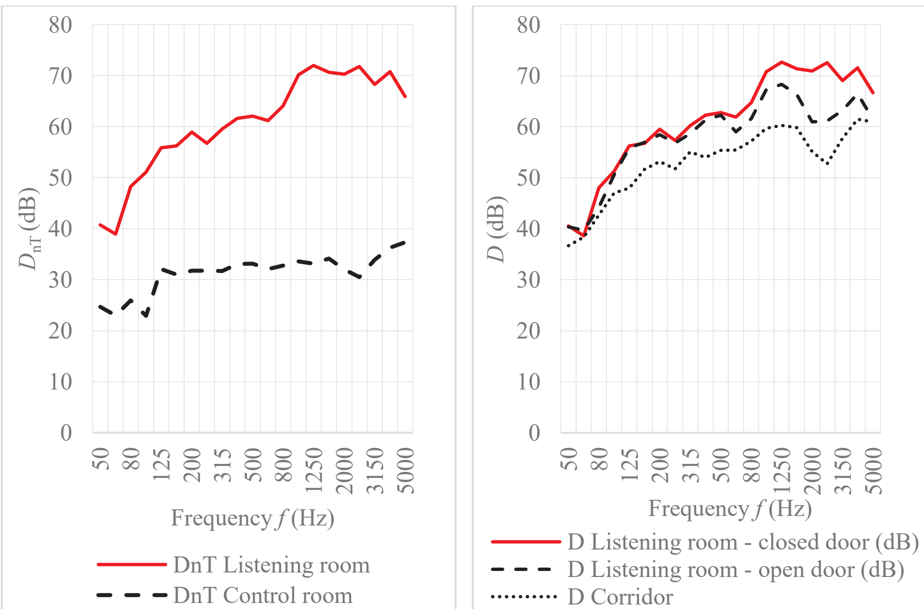

Figure 7 Frequency-dependent values of airborne sound insulation D_{nT} of the walls between corridor and the listening room and control room respectively (left) and the influence of the glass wall to reduce the noise level D (right).

4.3 Equivalent sound pressure level

The background noise was measured during a most busy hours, i.e. from 6:00 to 11:00. The measurement was performed using a Norsonic Nor140 analyser. The values of the equivalent sound pressure level $L_{A,eq}$ and percentile values of noise levels $L_{A,95}$ and $L_{A,10}$ were calculated.

In Figure 7-left we can see the equivalent sound pressure level measured in the listening room and control room. The effect of the increase in airborne sound insulation of the listening room compared to the control room is reflected in all third octave bands from 50 Hz to 20 kHz. However, the highest influence is from the frequency band 50 Hz to 5000 Hz. This interval corresponds to the maximum spectral width in the evaluation of structures in terms of building acoustics [12]. The total A-weighted equivalent sound pressure level reaches 17 dB in the listening room and 31 dB in the control room.

The level of almost constant noise $L_{A,95}$ is 16 dB in the listening room and 31 dB in the control room. The noise levels $L_{A,10}$ was measured as high as 20 dB in the listening room and 35 dB in the control room. We can see that the noise dispersion in the listening and control room is the same, i.e. 4 dB. However, thanks to adaptation of surrounding constructions, the noise level in the listening room was reduced by 14 dB in the case of $L_{A,eq}$ and by 15 dB in the case of the levels $L_{A,95}$ and $L_{A,10}$.

The equivalent sound pressure level in the building exterior was also measured at a distance of 2 m in front of the façade at a height of 10 m above the ground (3rd floor) and at a height of 73 m above the ground (22nd floor). Figure 7-right shows the frequency-dependent course of equivalent sound pressure level. The A-weighted equivalent sound pressure level in height of 10 m was in average 63 dB; and it reached 58 dB in hight of 73 m. Thanks to the maximum possible increase in the distance of the listening room from traffic noise, the equivalent sound pressure level was reduced by 5 dB.

5 Conclusion

This article focuses on a conversion of an office space to an acoustic laboratory dedicated to performance of listening tests with minimal costs. Challenges on adaptation of a space with mild acoustic requirements to a space with increased acoustic requirements are shown.
First, the analysis of potential noise sources has been performed and most convenient position of the listening room in the building has been chosen. The measured difference in equivalent sound pressure level at a distance of 2 m in front of the facade was at the 22nd floor (where the lab is finally situated) 5 dB lower in comparison with pedestrian ground floor level.
Later, several steps in terms of improvement of airborne sound insulation of partition walls and building façade were made. The sound insulation after the improvements have reached a D_{nT} value of 67 dB, while the D_{nT} of the original partition wall was only 33 dB.
The background noise expressed in equivalent sound pressure levels $L_{A,eq}$ and statistical values of $L_{A,95}$ and $L_{A,10}$ were also significantly reduced. The $L_{A,eq}$ in the listening room does not exceed 17 dB, while the background noise in the control room (representing the situation without any interventions) is around 31 dB. The $L_{A,95}$ in the listening room is around 16 dB, while in the control room it reaches 31 dB. The $L_{A,10} = 20$ dB in the listening room and 35 dB in the control room.
Finally, adjustments were made also in terms of room acoustics, by placing the highly sound absorbing material on wall and ceiling surfaces. Floor is covered by carpet.
It can be concluded that the transformed room is now quiet enough and suitable for the research where laboratory listening test are used.

6 References

[1] "Director-General's Opening Remarks at the Media Briefing on COVID-19-11 March 2020," WHO, [Online]. Available: https://www.who.int/director-general/speeches/detail/who-director-general-s-opening-remarks-at-the-media-briefing-oncovid-.

[2] Y. Sluyts, L. TingChun, D. Urbán and M. Rychtarikova, "The effect of mask wearing on speech intelligibility in various architectural environments in schools," in *In proceedings of Euronoise*, Madeira, 2021.

[3] M. Buschka, J. Bischof, C. Meier-Dotzler and W. Lang, "Developing non-residential building stock archetypes for LCI - a German case study of office and administration buildings," *The International Journal of Life Cycle Assessment,* vol. 26, no. 9, pp. 1735-1752, 2021.

[4] H. Ogawa, K. Kobayashi, N. Sunaga, T. Mitamura, A. Kinoshita, S. Sawada and S. Matsumoto, "A study on the architectural conversion from office to residential facilities - through three case studies in Tokyo," pp. 171-178.

[5] B. Clifford, J. Ferm, N. Livingstone and P. Canelas, "Overview of Office-to-Residential Conversion in England and Our Case Studies," *Understanding the Impacts of Deregulation in Planning,* pp. 47-60, 2019.

[6] C. Monteiro, M. Machimbarrena, D. de la Prida and M. Rychtarikova, "Subjective and objective acoustic performance ranking of heavy and light weight walls," *Applied Acoustics,* vol. 110, pp. 268-279, 2016.

[7] P. Virjonen, V. Hongisto and J. Radun, "Annoyance penalty of periodically amplitude-modulated wide-band sound," *The Journal of the Acoustical Society of America,* vol. 146, no. 6, pp. 4159-4170, 2019.

[8] C. Calleri, L. Shtrepi, A. Armando and A. Astolfi, "Evaluation of the influence of building façade design on the acoustic characteristics and auditory perception of urban spaces," *Building Acoustics,* vol. 1, no. 25, pp. 77-95, 2018.

[9] IEC TR 60268-13 Sound system equipment - Part 13: Listening tests on loudspeakers, 1998.

[10] ISO 3382-2 Acoustics - Measurement of room acoustic parameters - Part 2: Reverberation time in ordinary rooms, 2008.

[11] ISO 16283-1 Acoustics - Field measurement of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation, 2014.

[12] ISO 717-1 Acoustics — Rating of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation, 2013.

[13] V. Chmelík, M. Rychtáriková, H. Müllner, K. Jambrošić, L. Zelem, J. Benklewski and C. Glorieux, "Methodology for development of airborne sound insulation descriptor valid for light-weight and masonry walls," *Applied Acoustics,* vol. 160, 2020.