

Acoustic properties of façade fragments of historical monuments

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ABSTRACT

Retrofitting of historical monuments in terms of their improvement in energy performance and overall sustainability is one of the frequently discussed questions in building sector and architecture. However, the renovation of monuments is highly interdisciplinary task and therefore, the global assessment of proposed solutions is needed.

In this article we discuss the impact of additional thermal insulation in historical buildings while keeping the reversibility of the action, on its sound insulation performance. Typical cases of energetic retrofit in Slovakia are shown and sound transmission index R (dB) is predicted in Norflag software 4.0 that uses transfer matrix method as calculation algorithm. The solutions are discussed in term of its thermo – acoustic performance.

Keywords: Architectural heritage, Thermal and Sound Insulation, Building acoustics

1. INTRODUCTION

During the last decades many research projects and initiatives have been undertaken, that deal with the energy efficiency and various comfort issues in historic buildings (1). Most of the previously performed research has been focused on moisture and humidity transfer in constructions of buildings, insulated from inside, typical in cases where the insulation from exterior side is not acceptable because of art-historical decoration or authenticity of the façade. Preservation of architectural heritage also doesn't always allow for invasive ways of building envelope restoration. The methodology for improvement of energy efficiency and sustainability of historic buildings is therefore mostly based on solutions with reversible technologies (4).

The impact of different proposed renovation solutions has been already sufficiently investigated in terms of thermal comfort, however only little attention has been given to their consequences on other aspects, such as sound insulation. This paper is a part of systematic investigation of thermal and acoustic insulation in historic buildings where energy efficiency and thermos-acoustic comfort (5) should be put in balance, while preserving their architectural authenticity.

The presented study is based on a simple experiment in which 3 types of historical walls (stone masonry of 600 mm, brick masonry of 450 and 300 mm thick) are thermally insulated. For each type of wall, 3 solutions of thermal retrofit are considered in a way to have the same U-value of ca 0.21 W/(m².K). The differences in acoustic performance as calculated in Norflag software are shown and discussed.

2. DESCRIPTION OF THE CASE STUDY

The study is structured in the following parts: (i) choice of historic masonry constructions, (ii) selection of the thermal insulation variants, (iii) assessment of the acoustic benefits related to the insulation variants.

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2.1 Definition of types of historic masonry walls

Study has been applied on selected representatives of masonries of traditional historic buildings from Central Europe area. Based on the literature review and other available materials, two basic groups of envelope structures were defined, presenting the basic principles of architectural culture of the past centuries and forming the structures of dominant group of preserved architectural heritage: masonries based on stone and brick elements.

The difficulty of the process to select suitable representatives was to define appropriate dimensions, especially of stone masonry type, as unification was not used in historical construction and many different factors influenced the design of this structures. 600 mm thick sandstone wall was chosen to represent the stone masonries of historic buildings, the most common variant in terms of materiality of investigated territory. Although the chosen thickness does not represent an average value, it is the most appropriate representative for stone masonry in terms of application the thermal insulation. Brick fragment is made up of solid silicate bricks at a total thickness of 450 mm, which can be said to be the most common brick wall variant in Central Europe. The last group can be considered as an academic example of brick masonry with 300 mm thickness and was chosen for sake of comparison with cases where the initial sound reduction index is initially low.



Figure 1 – Typical Slovakian gothic burgher house with 600 mm thick stone (sandstone) wall (left picture) and typical town house from turn of the 19th and 20th century with 450 mm thick brick wall (right picture)

2.2 Selection of Thermal Insulation Variants

The external envelope is the most exposed part of building and therefore must fulfill certain acoustic and thermal requirements. In case of historical heritage, monuments or in cases in which buildings have a cultural value, façade is sensitively perceived and thoroughly protected. These facts often result in discussions in terms of building renewal. The presented results aim at the impact of the additional thermal insulation of the building façade, which can be applied in three different ways, exterior insulation and two types of thermal insulation placed from building interior.

Most effective strategy in renovation of existing buildings related to the energy consumption and the improvement of indoor environment is the use of exterior thermal insulation of the façades. However, this solution is not always applicable to objects with historical and architectural value, as well as objects protected by monument rule, as they meet the requirements for preserving the original appearance of the façade. An alternative and nowadays very popular way of increasing the thermal protection of buildings envelope is the interior application method of thermal insulation, which is often the only possible solution.

For the study, the following cases were chosen (Figure 2): Three types of of the abovementioned masonry types 600 mm stone, 450 mm brick and 300 mm brick) were chosen and for each, 3 different systems of facade insulation were applied. The thermal protection aspects are in all cases set to meet the current requirements of energy performance of renovated buildings. From the material point of view, it is the use of mineral wool in different thickness depending on (i) material base of masonry, (ii) position and (iii) technology of application of insulation material. In the example of the external thermal insulation the extruded polystyrene (EPS) with very thin layer of plaster was used.

The selection of the insulation variants aims at comparing the acoustic benefits of different systems.

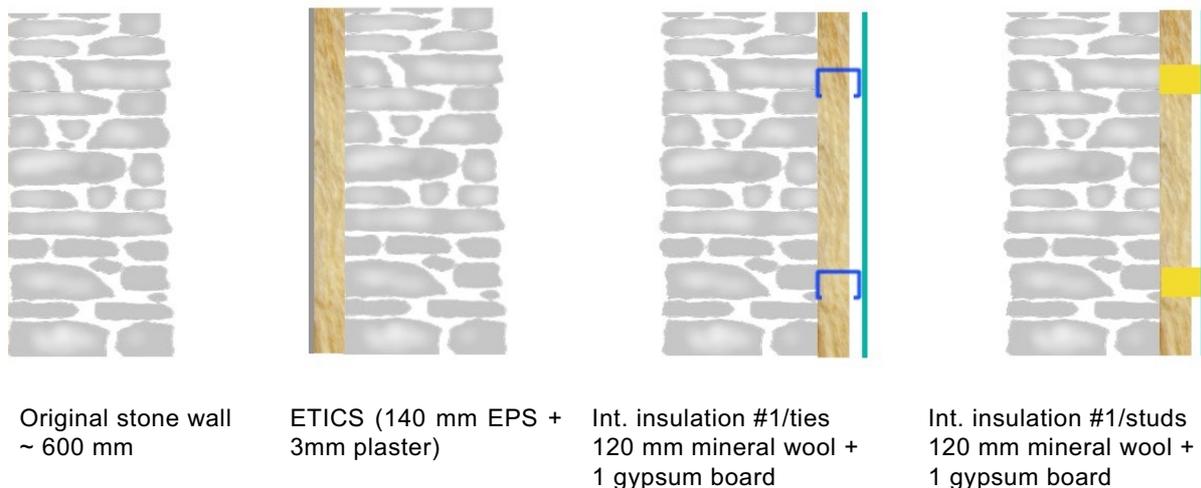


Figure 2 – Simulated stone wall fragments – thermal insulation variants

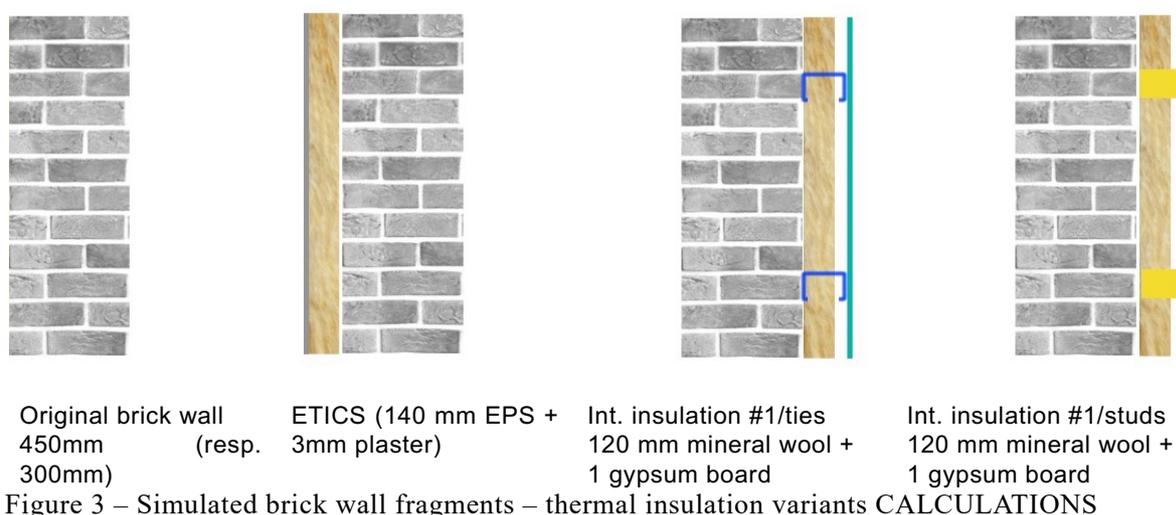


Figure 3 – Simulated brick wall fragments – thermal insulation variants CALCULATIONS

2.3 Description of the calculation algorithm

Simulations were performed in the acoustic software Norflag 4.0. Norflag, known also as WinFlag software) is made to calculate the theoretical sound reduction index R (dB) for constructions that can be combined by different types of layers of different materials (11). Simulation algorithm allows for calculation of mean values in one-third-octave bands using the transfer matrix method. Calculations can be performed for chosen angle of incidence or for diffuse sound field.

In the calculation, each layer is assumed to be an infinite plate and is presented by a matrix which is combined with other matrix layers. The two types of plates can be chosen for the prediction of sound insulation of wall: thin plates and thick plates. Thin plates are chosen in cases in which the wavelength of a bending wave is large than 6x thickness of the given plate. In this case 2x2 matrix is used since there is no question about the wave motion inside the plate. Porous layers are simulated in the same way, by 2x2 matrixes. In cases, where the two layers are glued together, thick plate description comes into consideration as one layer should be then describing both of the layers as thick plates. Calculations using the thick plate method are applicable for wall constructions of sandwich elements which are glued together and are then described by a 4x4 matrix.

For sake of comparisons in the article, the sound reduction index R (dB) and the weighted sound reduction index R_w (C, C_{tr}) in dB was calculated. Sound transmission simulations were performed in third octave bands in diffuse field (i.e. with integration angles from 0 to 90 degree), and transmission window of 10 m².

3. RESULTS AND ANALYSIS

Results of simulated sound transmission are summarized in graphical way, by means of the following figure (Fig.4) and Table 1. The results show the sound reduction index for all cases, grouped in three graphs. In all cases a significant improvement can be seen when insulation is applied from inside. When only little contact is used to connect the plaster board, the R_w increases with 10-11 dB, in cases with studs are used sound insulation increases with around 8 dB. In both cases of mass spring mass systems we can see the coincidence dip of the masonry wall at low frequencies (and a dip at around 2500 Hz, caused by gypsum board of 12 mm. 100 Hz for brick wall of 450 mm and similar to stone wall, since these has less density and lower Young modulus (brick wall 600 mm thick would have coincidence frequency around 75 Hz). The brick wall of 300 mm has coincidence at 150 Hz.

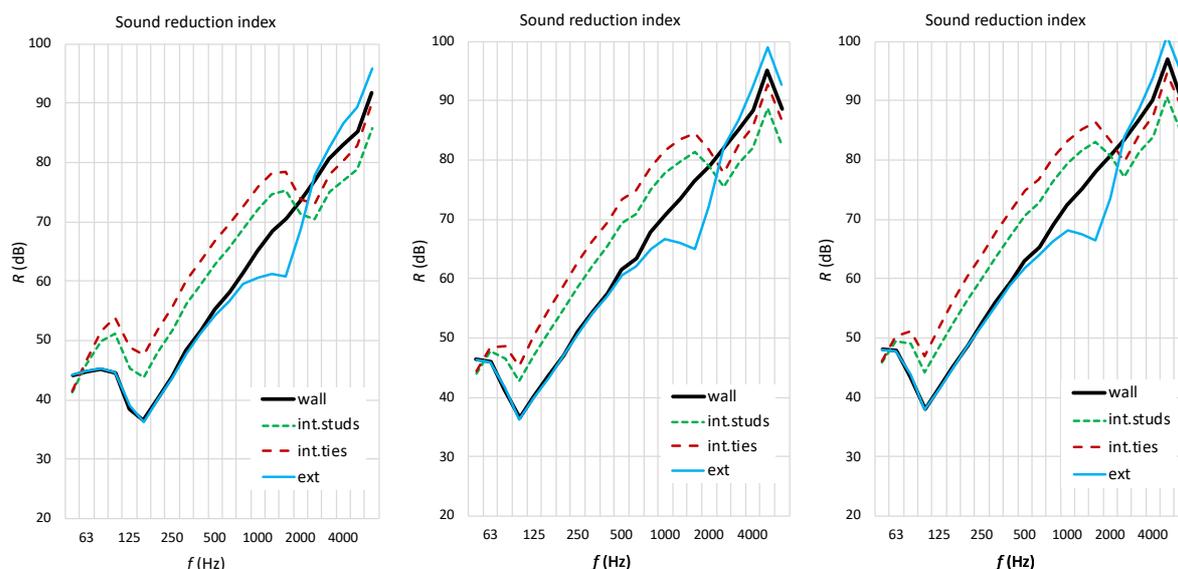


Figure 4 – Simulated variants. Left – variants for brick wall 300 mm, Middle figure – variants for brick wall 450 mm, Right picture – variants of 600 mm stone masonry wall. (black thick line shows the Sound transmission index R (dB) of the original wall without thermal insulation (TI). The green dashed line expresses the internal TI fixed by ties, red dashed line when fixed by studs. Blue line is the situation with layer of EPS applied on the facades from outside.

The three cases with polystyrene (EPS) applied on a façade from the building exterior show similar behaviour. The EPS was simulated as connected with ties to the masonry wall, presuming a gap of 0.5-1mm between the wall and EPS boards caused by irregularities of the historical wall. The visible dip around 2000 Hz can be seen in simulations of all wall thicknesses.

Table 1– Results of weighed sound reduction index $R_w(C, C_{tr})$

Weighed sound reduction index $R_w(C, C_{tr})$ in dB	No insulation	EPS	Int. Insul. #1 ties	Int. Insul. #2 studs
Stone masonry (600 mm)	63 (-2,-8)	62 (-2;-8)	74 (-3;-9)	70 (-2;-9)
Brick masonry (450 mm)	61 (-2,-8)	61 (-2,-8)	72 (-2;-9)	69 (-3;-9)
Brick masonry (300 mm)	56 (-2,-6)	56 (-2,-6)	68 (-3;-7)	64 (-2;-7)
Heat transfer coefficient U [W/(m ² .K)]	1,20	0,21	0,22	0,22

4. CONCLUSIONS

When restoring the architecturally valuable façade, increased attention should be paid to the degree of intervention to the origin and the resulting impact on the authenticity of the object, whether in terms of material authenticity (physical matter of object) or the authenticity of the whole work (cultural-historical essence of the monument). Here, the placement of thermal insulation from inside has in the winter period many disadvantages when looking purely to humidity and moisture transfer.

This is however true only in winter time and renovation of historical monument must be always considered in given climate.

From the point of view of acoustics, the simulations have yield the acoustic benefits of the thermal insulation variants in which the insulation was placed from inside the building. This paper have shown only simulations of typical wall fragments. In reality, the sound insulation of building façade is much more complicated issue and must be therefore considered as a whole, including windows and doors.

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