The effect of additional thermal lining on the acoustic performance of a wall

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External thermal insulation composite systems (ETICS) are commonly used in Poland for thermo-retrofitting of old multifamily buildings as well as for proper insulation of new buildings constructed presently. Blocks of flats built in sixties and seventies are the main group subjected to thermo modernization. Additional insulating layer radically improves thermal performance of a wall but at the same time reduces its sound insulation in a certain frequency range depending on the resonance frequency of the wall-lining system. Usually the acoustic effect of thermo retrofitting is unnoticed by inhabitants as windows decide on the total sound insulation of a building envelope. The problem becomes important in the case of noisy locations.
The paper presents results of experimental investigation on the influence of lightweight linings on the acoustic performance of a massive wall. Different claddings, based on expanded polystyrene and mineral wool applied to basic walls made of calcium silicate blocks, cellular concrete and hollowed ceramics are considered. The effect of lining, its resonance frequency and influence on single number quantities is discussed as well as the problem of sound reduction index improvement prediction acc to EN 12354-1 and separate acoustical characteristics of a lining and testing acc. to ISO 140-16.

1 Introduction

As a result of implementation of Directive 2002/91/EC on the energy performance of buildings [1] substantial number of residential buildings in Poland is subjected to thermo-retrofitting usually by applying different lightweight external insulating systems (ETICS) based on expanded polystyrene or mineral wool finished with thin synthetic or mineral plaster. ETICS are used for old residential buildings from the beginning of twentieth century as well as new apartment buildings constructed presently (fig. 1). However blocks of flats, which were erected mostly in sixties and seventies using industrialized methods, are the main group of buildings that need additional thermal insulation.

Fig. 1 ETICS applied to an old residential building constructed in 1910 and the same system used for a new building under construction in 2008.

Thermal works are beneficial form the energy conservation view point but in most cases they produce adverse side effect by decreasing the sound insulation of a wall within certain frequency range. In general designers, developers, authorities and other stakeholders are not aware of the acoustic effect of additional lining applied to a massive wall. Usually it does not reduce the total sound insulation of a building envelope substantially because the performance of windows, air inlets and ventilators plays the pivotal role to its value. The acoustical problems can appear in noisy building locations, particularly for corner rooms which have more than one external wall. The effect of additional lining can be perceived by inhabitants as a new noise source because the spectrum of noise penetrating into the room is considerably modified by applying the cladding. The subjective feelings after thermo-retrofitting may result from combine effect because additional thermal lining is often accompanied with installation of new windows which have different sound insulation than original and also modify the spectrum of noise penetrating from outside.

Actually the problem of acoustic performance of additional thermal lining is not precisely defined. One question is the acoustical characteristics of a specific lining system considered as a separate building product. The other is the possible prediction of a lining behavior when applied to a wall of a particular structure which is complicated as the acoustic effect depends on the lining as well as the performance of a basic wall itself.

The paper presents results of laboratory tests carried out for different lightweight linings applied to different basic walls. The measurements were intended partly to investigate the possibility of reducing the adverse acoustical effect.

2 Testing method

The method of determining the acoustic performance of a lining is defined in ISO 140-16:2006 [2]. According to the standard general characteristics of a lining alone should be measured on heavy basic wall with a mass per unit area of 350±50 kg/m^2 with its critical frequency located in the 125Hz octave band. The wall can be made of concrete, concrete blocks or masonry with no cavities apart from grip holes and no thickness resonance below 3150 Hz. The sound insulation improvement by the lining is given as a frequency spectrum and single number indicators. Beside direct difference of the weighted sound reduction indices,

ΔR_w, $\Delta(R_w+C)$ and $\Delta(R_w+C_{tr})$, which are simple difference of the sound reduction indices of the basic wall with and without the lining, also weighted sound reduction improvement index may be calculated in a similar way as a weighted reduction in impact sound pressure level for floating floors. The results can be used to characterize performance of considered lining as a building product or to predict the sound insulation when applied to a heavy wall of a structure similar to the standard basic wall.

In practice an external wall usually does not correspond to reference heavy basic wall defined by the standard. Most frequently it is made of cellular concrete or hollow ceramics. The lining applied to such walls should be considered individually and only direct difference of the weighted sound reduction indices of the specific basic element with and without lining can be calculated. The results should not be used for prediction when the lining is used for another basic wall of different structure. It means that in terms of acoustic such a wall should be considered as the final product together with lining, as in practice the acoustic performance of the wall with lining can not be derive precisely from the performance of its elements.

3 Estimation of ΔR_w acc to EN 12354

The European calculation model for the acoustic performance of buildings from the performance of elements distinguishes the improvement of the sound reduction index by an additional lining [3]. It assumes that if the lining is fixed to a homogeneous basic structural element the airborne sound insulation can be improved or reduced. It depends on the resonance frequency which can be calculated from equation:

$$f_0 = 160\sqrt{s'\left(\frac{1}{m'_1}+\frac{1}{m'_2}\right)} \qquad (1)$$

Where:

s' is the dynamic stiffness of the insulation layer according to EN 29052-1, MN/m^3;

m'_1 is the mass per unit area of the basic element, kg/m^2;

m'_2 is the mass per unit area of the additional layer, kg/m^2.

EN12354-1 gives the estimation of weighted sound reduction index improvement by a lining (ΔR_w) depending on the resonance frequency f_0. When f_0 is higher than 160 Hz the value of ΔR_w is negative and decreases with resonance frequency increase, for f_0 within 630 - 1600 Hz range it gains -10 dB. The other A-weighted single number indicators, $\Delta(R_w+C)$ and $\Delta(R_w+C_{tr})$ are not mentioned.

4 Test results

4.1 Lining applied to a heavy basic wall

Two different thermal linings were tested on the same massive wall constructed of calcium silicate blocks, 240 mm thick, one side plastered, with total mass per unit area of 356 kg/m^2. There are four ∅60 mm cylindrical hollows in each block which in total take less than 6% of the whole block surface area and not pierce it totally as they are 30 mm shorter than the block height. The critical frequency occurs around 125-160 Hz. The wall corresponds to the heavyweight basic wall defined by ISO 140-16. Sound insulation characteristic of the wall tested, and standard reference curve for basic wall with low coincidence frequency is shown in fig. 2.

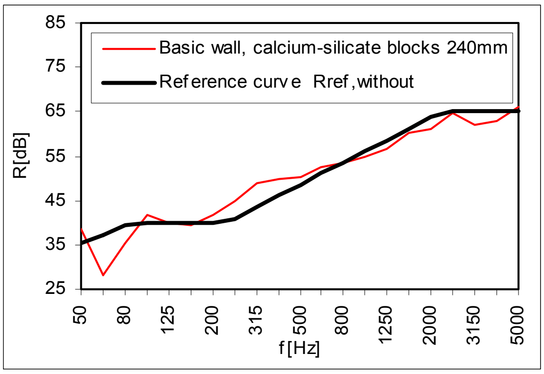

Fig. 2 Sound insulation characteristic of basic wall made of calcium silicate blocks, 240 mm thick.

Both linings applied to the wall belong to the same insulation system which consists of external acrylic plaster 6mm thick with mass per unit area of about 8 kg/m^2 and possible different thermal insulating layer. For the wall tested two different materials i.e. expanded polystyrene (EPS) and mineral wool (MW) were used. The characteristics of materials; thickness (d), mass per unit area of insulating layer (m_2) and plaster (m'_2), dynamic stiffness (s'), and the resonance frequency (f_0) calculated from formula (1) are shown in table 1.

Lining	d mm	m_2 kg/m^2	m'_2 kg/m^2	s' MN/m^3	f_0 Hz
EPS	150	2,1	8	25	283
MW	150	12,2	8	46	384

Table 1Characteristics of materials used for linings.

The application of lining causes the increase of sound insulation in the high frequency range and decreases it at low and medium frequencies (fig. 3). The resonance frequency is 315 Hz for expanded polystyrene and around 125 Hz for mineral wool lining. In the case of EPS it matches well with the value calculated form equation (1) based on dynamic stiffness data.

For the wall with mineral wool lining the real resonance frequency is different than calculated so the question rises about the dependency of mineral wool dynamic stiffness on static load applied to the specimen. When tested in accordance with ISO 9052-1 the load is 200 kg/m^2 while in real situation the mass of lining's plaster is about 8 kg/m^2. The behavior of mineral wool under standard loading, which is typical for floating floors, may be different than when it is used to a wall with no load, just a small mass fixed to it vertically. ISO 9052-1 says about possible

10-20% difference but in our case the difference is much bigger. Dynamic stiffness of investigated mineral wool was also tested with another preload. When it was higher than standard 200 kg/m^2, the results were more or less the same within 20% margin. When the real 8 kg/m^2 was applied the resonance frequency occurred around 125 Hz, however its position was not very clear due to high internal damping.

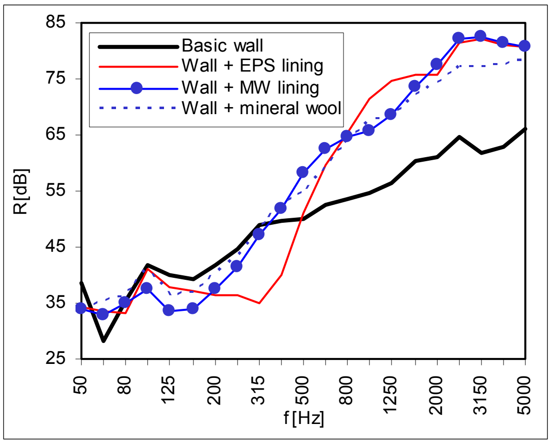

Fig. 3 Results of laboratory test, basic calcium silicate wall with linings made of EPS and mineral wool (MW).

The sound insulation of considered calcium silicate wall was also measured with mineral wool only glued to its surface i.e. without any external layer of acrylic plaster. The effect of sound insulation reduction is not as evident as for complete lining but clearly occurs at the same frequency range (fig. 3). It may be concluded that the low resonance frequency depends on the mineral wool itself more than on the mass of plaster. In the case investigated the effect coincides with the critical frequency of the basic wall but in practice it occurs also for other structures.

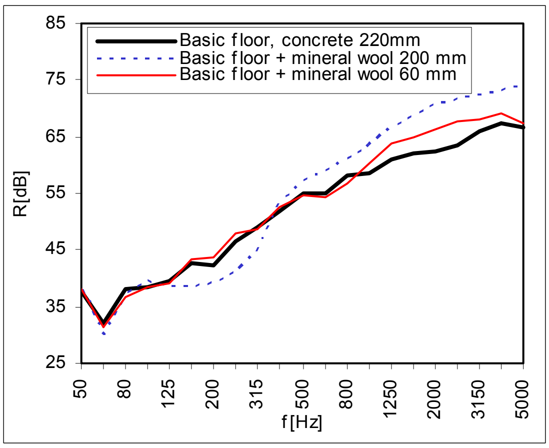

Fig. 4 Sound insulation of a concrete floor 220 mm thick with mineral wool alone fastened to it.

Insulating layer in a form of just mineral wool alone is often used for floors separating the space of garage from dwellings above it. It is applied due to thermal and fire protection reasons. Figure 4 shows the results of laboratory measurements carried out for basic concrete floor 220 mm thick with 200 mm mineral wool fastened to it on the bottom side. The tendency is clear and similar to observed in fig. 3. The reduction of sound insulation does not influence significantly values of single number indicator, however around 250 Hz the decrease ranges about 6 dB. Such a reduction gets its importance when noisy technical equipment, with low frequency tonal spectrum, is located beneath the floor. It is quite difficult to increase the sound insulation of massive partition by 6 dB in low frequency area. The effect of thinner 60 mm mineral wool applied to the same floor is merely visible. The resonance is moved toward 630 Hz.

The values of direct differences of the weighted sound reduction indices for the calcium silicate wall tested with both linings are collected in table 3. In the case of expanded polystyrene the value of $\Delta R_{w,direct}$ is close to predicted based on the method laid in EN12354 [3] which gives ΔR_w = -5dB. For the mineral wool lining, when considering the real resonance frequency observed in fig. 1, the predicted value is +3dB so appears quite different from what was measured. When taking the resonance frequency calculated theoretically form formula (1) and dynamic stiffness data (table 1) the difference is even bigger.

In terms of rating method interesting is the relationship between $\Delta R_{w,direct}$ and A-weighted indicators because EN12354 gives no information about it. For (R_w+C_{tr}) index, which is often used as a main assessment tool for external walls, the value of $\Delta(R_w+C_{tr})_{direct}$ tends to be 2-3 dB lower than $\Delta R_{w,direct}$ due to low frequency behavior of the linings.

Lining	$f_{0,m}$ Hz	$\Delta R_{w,direct}$ dB	$\Delta(R_w+C)_{direct}$ dB	$\Delta(R_w+C_{tr})_{direct}$ dB
EPS	315	-4	-5	-6
MW	125	0	-1	-3

Table 3 Single number quantities for linings applied to calcium silicate basic wall, results of measurements.

Another question is if the single number quantity rating reflects properly the real acoustic effect of lining and related to it subjective fillings of inhabitants [4]. As a result of EPS lining application the drop of sound insulation around the resonance frequency ranges 14 dB. In the case of intensive road traffic noise, for which low frequency sound pressure level dominates in the spectrum, such a lowering may be found annoying in spite of relatively high values of single number indicators.

Weighted sound reduction improvement indices calculated in accordance with ISO 140-16 [2] based on measurement results and low coincidence frequency reference curve are shown Table 4.

Lining	ΔR_w dB	$\Delta(R_w+C)$ dB	$\Delta(R_w+C_{tr})$ dB
EPS	-7	-8	-7
MW	-1	-2	-3

Table 4 Single number quantities for linings calculated based on measurements data and reference curve acc to [2].

4.2 Cellular concrete

External wall made of heavy elements corresponding to standard heavy basic wall and low coincidence frequency reference curve is rather rarely used in presently constructed buildings. The problem of a lining applied to heavy massive wall refers rather to old buildings subjected to thermo-retrofitting works. In the case of new buildings more lightweight structure of an envelope e.g. cellular concrete or hollow ceramics is more typical. Theoretical prediction of the acoustical effect of a specific lining on such a wall is tricky because it depends also on the basic wall performance.

From so far experiences and practical approach given by EN standard [3] results, that the influence of lining on the weighted sound reduction index R_w is not so destructive when the resonance frequency is located low. Resonance frequency may be shifted lower by reducing dynamic stiffness of the insulating layer or increasing the mass of plaster. In practice both possibilities are quite restricted because the thickness of thermal insulation and surface mass of a plaster is determined by thermal and mechanical reasons. However, different insulating materials with different dynamic stiffness can be used.

Fig. 5 illustrates the effect of three different linings applied to the same wall made of cellular concrete. The wall was 250 mm thick, one side plastered. Linings were made of mineral wool 100 mm (M), expanded polystyrene 100 mm (EPS) and elastic expanded polystyrene 150 mm (E-EPS) which is designated for use in floating floor rather than external insulating systems. The sample of E-EPS was produced especially for the purpose of testing its effect on the wall as a possible new application.

The use of elastic expanded polystyrene gives the best results at medium and high frequencies due to low position of resonance, the sound insulation characteristic looks advantageous comparing to the other curves.

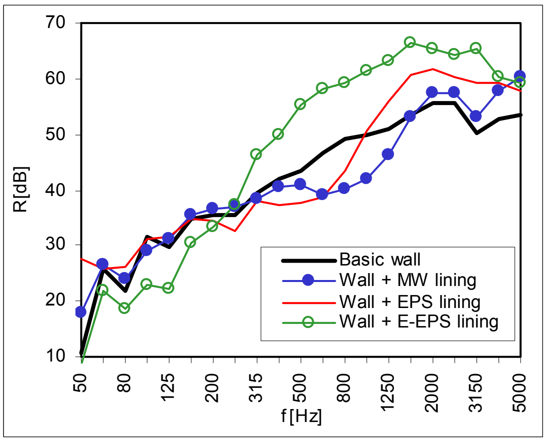

Fig. 5 Results of laboratory tests, cellular concrete wall with linings made of EPS, E-EPS and mineral wool (MW).

Single number quantities and resonance frequency observed for tested linings are shown in table 5. In the case of expanded polystyrene (EPS) and mineral wool (MW) the values of direct difference of weighted sound reduction indices are practically the same. As the resonance frequency for both linings is at medium frequencies the reduction of R_w value is bigger than reduction of A-weighted indicators. In the case of elastic expanded polystyrene (E-EPS), the situation is converse, the lining badly influence the $\Delta(R_w+C_{tr})$ index value.

Lining	f_0 Hz	$\Delta R_{w,direct}$ dB	$\Delta(R_w+C)_{direct}$ dB	$\Delta(R_w+C_{tr})_{direct}$ dB
EPS	630	-4	-3	-2
E-EPS	80	0	-1	-5
MW	800	-4	-3	-3

Table 5 Single number quantities for different linings applied to cellular concrete wall, results of measurements.

4.3 Hollowed ceramics

Hollowed ceramics is the other material most often used for external wall. As the structure is not homogenous the prediction of the acoustic effect of additional lining is rather complicated. Fig. 6 shows the results of laboratory measurements carried out for three different linings applied to the same basic wall made of hollowed porous ceramic elements. The wall was 380 mm thick one side plastered. Linings were made of expanded polystyrene 100 mm (EPS), mineral wool 100 mm (MW) and special kind of soft mineral wool 100 mm (MW-dd) designed for application directly to the wall without any studs or supporting frame. Measurements were intended to investigate the influence of different mineral wool performance on the acoustic behavior of a lining.

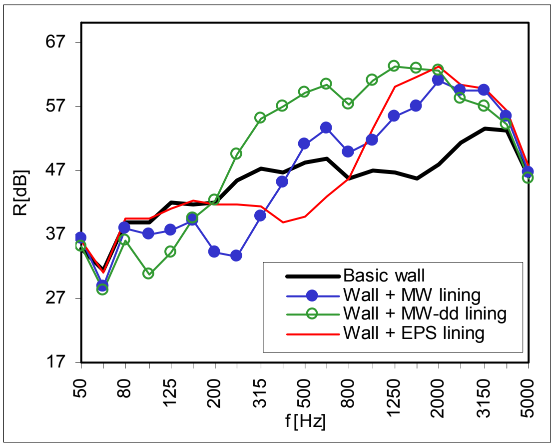

Fig. 6 Results of laboratory tests, hollow ceramics wall with linings made of EPS, mineral wool (MW) and soft mineral wool (MW-dd).

The use of soft mineral wool results in significant resonance frequency lowering and causes the expansion of range in which the sound insulation improves. Single number quantities are collected in table 6. The effect of soft mineral wool application seams promising. The improvement of (R_w+C_{tr}) is much lower than R_w index, however still it is positive value.

Lining	f_0 Hz	$\Delta R_{w,direct}$ dB	$\Delta(R_w+C)_{direct}$ dB	$\Delta(R_w+C_{tr})_{direct}$ dB
EPS	400	0	-1	-1
MW	250	2	0	-2
MW-dd	100	8	6	2

Table 6 Single number quantities for different linings applied to hollowed ceramics wall, results of test.

Fig. 7 presents the effect of soft mineral wall alone applied to the basic wall. The tendency is the same as in the case of stiff mineral wool shown in figures 3 and 4. It confirms that the resonance frequency may depend on the mineral wool performance more than on the mass of plaster.

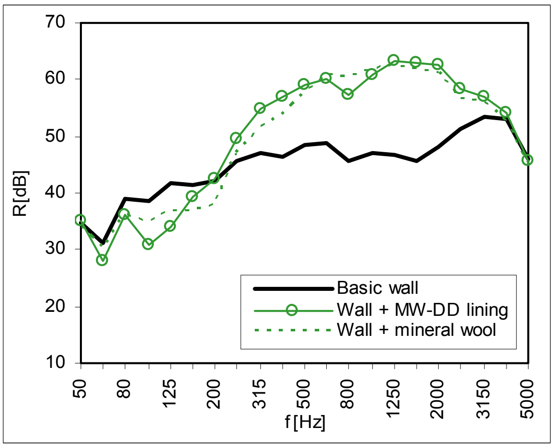

Fig. 7 Results of laboratory tests, hollow ceramics wall with lining made of mineral wool (MW-dd), and the same wall with mineral wool alone.

5 Conclusion

Application of lightweight thermal insulation linings is beneficial form the energy conservation view point but in most cases it produces adverse side effect by decreasing the sound insulation of a wall within certain frequency range. The effect can be moderate by using insulating material of proper dynamic stiffness and high internal damping.

New materials like soft mineral wool or elastic EPS are promising in acoustic terms. However, their practical application on a large scale depends on fulfilling remaining requirements.

The lowering of resonance frequency causes the increase of ΔR_w value but usually brinks about contrary effect to $\Delta(R_w + C_{tr})$ index. As the influence of a resonance frequency location is not the same for different indicators, the practical method of ΔR_w prediction given by EN standard [3] can not be applied directly to $\Delta(R_w + C_{tr})$ index.

As the A-weighted indicators are more adequate than R_w for the assessment of external wall so it should be discussed if based on new experiences it is possible to complement the practical EN prediction method with A-weighted sound reduction index improvement.

The question rises if the single quantity rating reflects properly the effect of lining and subjective fillings of inhabitants. The drop of sound insulation around resonance frequency may range several dB. In the case of intensive road traffic noise, for which low frequency sound pressure level dominate, such a lowering may be found annoying in spite of relatively high values of single number indicators.

For walls with mineral wool lining the real position of resonance frequency may be significantly different than calculated based on dynamic stiffness data. It may result from dependency of mineral wool dynamic stiffness on preload applied to the specimen when tested.

The effect of sound insulation reduction for a massive partition with mineral wool only glued to its surface is not as evident as for complete lining but clearly occurs at the same frequency range. It may be concluded that the resonance frequency depends on the mineral wool itself more than on the mass of plaster. Such insulating layer is often applied to a floor separating garage from dwellings so the acoustic effect of a lightweight insulation lining refers not only to the external walls.

References

[1] Directive 2002/91/EC of the European Parliament and of the Council of 16 December 2002 on the energy performance of buildings OJ L 1, 4.1.2003

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[3] EN 12354-1:2000 Building acoustics – Estimation of acoustic performance of buildings from the performance of elements – Part1: Airborne sound insulation between rooms

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