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Influence of the dynamic stiffness of external thermal insulation on the sound insulation of walls

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Summary

In view of the impact of applying an external thermal insulation composite system (ETICS) on the airborne sound insulation of walls being substantial, in this paper we report on the influence of the different dynamic stiffness of different thermal insulation layers on the sound insulation spectrum.

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1. Introduction

In order to reduce the energy performance of buildings and thus to achieve more ecological buildings there is a strong trend to refurbish thermal insulation systems in building constructions. The most common method in central Europe makes use external thermal insulation composite systems (ETICS). Insulating facades as well as roofs and other exposed surfaces can substantially increase the thermal resistance R(m^2.K/W) [1] of facades and enhance the building energy performance. The thermal resistance is ratio of material thickness d(m) and λ (W/(m.K)). Increasing demands in this direction have led to thermal insulation layers with thicknesses up to as high as 300mm (passive houses [2,3]), which is much more that common values in the 1980s, when the usual thickness of thermal insulation was 40-80mm.

The addition of material layers in the application of ETICS can also significantly influence the spectrum of the façade sound insulation, both in positive and negative way [4, 5]. Comparing the sound insulation spectrum after ETICS application to the one before, typically, both an increase of the acoustic insulation at high frequencies, and the appearance of a the resonance dip caused by a mass-spring-mass (m-s-m) resonance induced by the added outer layer and the added inner layer is found [4-9]. The m-s-m effect is caused by the combination of the basic wall acting as “mass 1”, the thermal insulation layer acting as “spring” and the thin solid external finishing layer acting as ” mass 2”. At and around m-s-m resonance, the enhanced acoustic impedance matching effect results in better energy transmission and therefore reduced acoustic insulation. Unfortunately, this resonance effect occurs usually in the audible spectrum. Several studies focused on an ETICS influence on the partition structures sound insulation have been reported [4-11]. Changes in single number rating due to the combined impact of ETICS at high frequencies (positive) and at the resonance frequency (negative) influence varying from -8 to + 19dB have been reported and several models predicting the ETICS induced modification of the sound reduction index ΔR (dB) have been proposed [5, 12-14].

In this paper we focus on the influence of the value of the dynamic stiffness of the thermal insulation layer on the sound insulation spectrum of wall. Several types of thermal insulation layers have been investigated by simulations and experiments. The presented work is based on theoretical results and measurement data published in [14, 15].

2. Prediction model

The used ΔR prediction model is based on a combination of theories by Weber et al. and Cremer (Eq. 2)[16]. The combined approach leading to Eq. (1) was presented in [14].

m'_1 is the total mass per unit area of massive basic wall (kg·m^{-2}); m'_2 is the mass per unit area of the used plaster (kg·m^{-2}). The "spring" of the system, (i.e., the thermal insulation placed in the cavity between the two rigid layers) is characterized by its dynamic stiffness s' (N·m^{-3}). η is the structural loss factor of the wall m'_1, ρ_0 (kg·m^{-3}) the density of air and c(m/s) speed of the sound in the plaster layer. Equation (1) can be applied for lower frequencies (frequency range up to one octave above the ETICS resonance frequency f_0(Hz)). Cremer's equation (Eq.2) is valid from that frequency up to the coincidence frequency f_c(Hz) of the ETICS mass part (the external plaster layer). The spectrum above f_c is linearly stable (0 dB/octave spectrum- based on measured results). It should be underlined that till now the model has only been tested just on the massive basic wall specified below. Therefore, also in this case study, we have investigated ETICS variations applied that particular wall.

$$\Delta R_{f<2.f_0} = 20\log\left(\sqrt{\frac{\left(1-\left(\frac{f}{\frac{1}{2\pi}\sqrt{s'\left(\frac{1}{m'_1}+\frac{1}{m'_2}\right)}}\right)^2\right)^2+4\left(\frac{\eta}{2}\right)^2\left(\frac{f}{\frac{1}{2\pi}\sqrt{s'\left(\frac{1}{m'_1}+\frac{1}{m'_2}\right)}}\right)^2}{1+4\left(\frac{\eta}{2}\right)^{2^2}\left(\frac{f}{\frac{1}{2\pi}\sqrt{s'\left(\frac{1}{m'_1}+\frac{1}{m'_2}\right)}}\right)^2}}\right) \quad (1)$$

$$\Delta R_{2.f_0<f<f_c} = 20\log\left(m'_2.\frac{f}{(\rho_0.c)}\right)+10log\left(\frac{f}{f_c}-1\right)+10\log(\eta)-2 \quad (2)$$

3. Case study details

The considered massive basic wall consisted of ceramic hollow bricks (220 mm) filled by concrete of the class C12/15. The wall was plastered by lime plaster with a thickness of 15 mm. The total surface mass density of the wall was m'_1 = 375 kg/m^2. The layer of lime plaster added on the thermal insulation was of surface mass density m'_2 = 28kg/m^2. The material properties were chosen based on measurements published in [15]. The idea was to choose different thermal insulation materials with the same thermal resistance (R=-3,64(m^2.K/W)).

The properties of eight selected nowadays used materials are listed in (Table 1)|. They differ in density, thermal conductivity and apparent dynamic stiffness. The listed values for the stiffness were derived based on equations in [15]. As shown in the table, the λ-values of nowadays thermal insulation materials lie in the range from 0,022 to 0,04(W/(m.K)), with between 13 and 112 kg/m^3. The simulated cases were conceived so that all thermal insulation layers had the same same thermal resistance, by appropriately varying their thickness between 0,08 and 0,015 m.

4. Results

Using the above equations, the sound reduction index R(dB), it's change compared to the original wall ΔR (dB), and the single number quantity R_w(dB) were calculated. Figure 1 shows that with increasing thermal insulation layer stiffness, the m-s-m dip moved to higher frequencies. The same effect is visible in the *R* spectrum (Figure 2).

Table I. Thermal insulation material properties

Name	λ (W/(m.K)	ρ(kg/m^3)	*d* (m)	*s* (MN/m^3)
Mineral wool 1	0,036	112,8	0,13	10,6
Mineral wool 2	0,04	96,6	0,15	9,0
Mineral wool 3	0,035	82,5	0,13	8,8
Mineral wool 4	0,036	53,1	0,13	4,4
Rigid foam	0,022	35,8	0,08	57,7
Grey EPS	0,031	14,8	0,11	42,0
Open EPS	0,04	14,3	0,15	33,0
White EPS	0,038	13,6	0,14	33,0

For all cases, application of an ETICS enhances the sound insulation above 400Hz, by virtue of the added mass. However, due to the m-s-m resonance, the dip in the insulation curves has a negative impact on the sound insulation at low frequencies.

Although for the mineral wool layers, the dip in the acoustic insulation spectrum do not affect the R_w-values, the low frequency spectrum and therefore the C and C_{tr} adaptation terms deteriorates significantly.

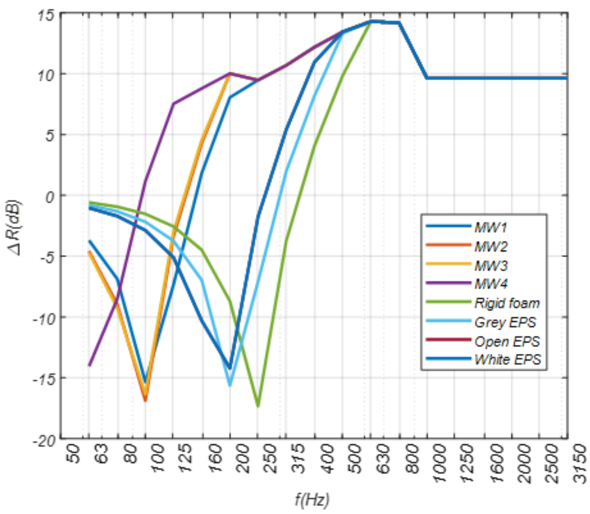

Figure 1. Sound reduction modification index ΔR (dB) for 8 ETICS variations.

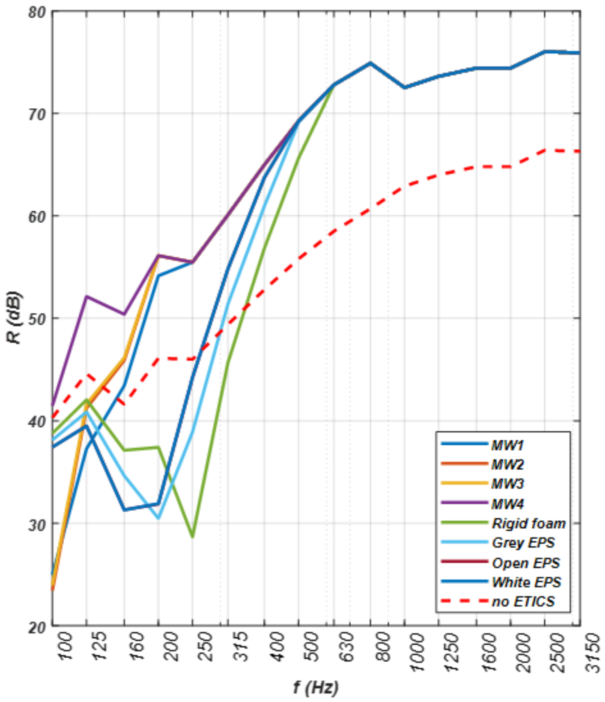

Figure 2. Airborne sound insulation spectrum. Comparison ETICS variations and the massive wall without ETICS.

Table II. Single number rating values of the simulated cases

Name	R_w(dB)	C (dB)	C_{tr}(dB)	s (MN/m3)
Mineral wool 1	61	-8	-16	10,6
Mineral wool 2	63	-11	-20	9,0
Mineral wool 3	63	-10	-19	8,8
Mineral wool 4	70	-3	-10	4,4
Rigid foam	53	-6	-10	57,7
Grey EPS	55	-5	-10	42,0
Open EPS	56	-6	-11	33,0
White EPS	56	-6	-11	33,0
No ETICS	59	-2	-6	

5. Conclusions

Simulation based results are presented on the relation between the dynamic stiffness of the thermal insulation layer in an ETICS and the impact of the ETICS on the sound reduction index, on the basis of 8 insulation layers applied on a typical massive wall. Besides showing the expected increase of the m-s-m dip frequency, the results also give a quantitative idea on the effect of a higher dynamic stiffness of the thermal insulation layer also on the acoustic insulation decrease in the frequency range around the typically low resonance frequency. For generalizing the results simulations and experimental validations will need to be done in which also the basic wall is varied. Additional work is also needed concerning the effect of the commonly used anchor fixing of the added layers onto the basic wall.

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