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The influence of thermal insulation selection on a facade sound insulation property – theoretical case study

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ABSTRACT

Impact of the external thermal insulation composite system (ETICS) on the sound reduction index improvement is widely discussed topic. ETICSs are already several years commonly used to reduce buildings thermal loses. However, its application can negatively influence facades sound insulation properties. In the high frequency range an additional thermal insulating layer improves the sound insulation property. However, in the low frequency range the sound insulation spectra rather often decrease. This decrease is caused by a mass - spring - mass resonance of the ETICS system. Location and the depth of resonance dip depend on the ETICS composition.
Several prediction models and measurement-based case studies were published already. In this contribution, an analytical model is used to predict the sound reduction index, using a measured dynamic stiffness of the ETICS system. A number of different thermal insulating layers are analysed having similar thermal properties but different material dynamic stiffnesses and loss factors. The comparison of theoretically predicted sound insulation spectra and the impact of the dynamic stiffness measurement technique are presented.

Keywords: Sound insulation, ETICS, prediction, facades, dynamic stiffness measurement uncertainty
I-INCE Classification of Subject Number: 30

1. INTRODUCTION

One of the most frequent solutions of buildings energy performance reduction is the building envelope constructions refurbishing by one of the external thermal composite system (ETICS) types applications. The thermal resistance R_t (m^2.K/W) [1] is defined as ratio of material thickness d (m) and thermal conductivity λ (W/(m.K)). By insulating the envelope constructions, the thermal resistance increases. It is one of the most common passive ways how to improve the thermal isolation properties of buildings. The

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requirements on the thermal insulation layer thickness of ETICS is increasing year by year. Whilst in 80ties of last century, the usual thermal insulation thickness was 40- 80 mm, nowadays is nothing unusual to meet with design of 300mm thick thermal insulation layer for so called passive houses [2,3].

As the ETICS application influences the thermal properties of the constructions, it can affect the acoustic sound insulation properties as well [4,5]. By additional layer (thermal insulation system lining) applied to the façade or roofing system, usually the sound insulation spectra in higher frequency range is increased. The low frequency spectra can be affected positively but also negatively, depending on the stiffness and damping of a ETICS. Unwanted resonance phenomena occur because of mass spring mass (m-s-m) behaviour of ETICS, where the massive wall (mass 1) and external plaster layer (mass 2) is connected via spring (usually thermal insulation with anchors). By sound wave or impact excitation the system starts resonate and makes the dip in the sound insulation spectra in the frequency range of the m-s-m resonance [4-9] (similar principle as in case of floating floor). Unfortunately, the resonance dip occurs at frequencies above 100Hz (within so called sound insulation spectra), which is audible. This topic was investigated in many publications already [4-11]. Generally, it was proved that, the combination of positive (high frequency range) and negative (low frequency spectra) ETICS effect on the sound insulation properties can lead to sound reduction index improvement ΔR_w (dB) ranging from -8 to +19 dB. However, how can one predict the influence of the chosen ETICS, before the refurbishing process will start? There were developed several prediction methods focused on numerical estimation of ETICS impact on the façade sound insulation [5,12-15].

This contribution is motivated, on the one hand, by recent works [14-16], where the prediction model of sound reduction index improvement spectra by ETICS was derived [14] and the impact of dynamic stiffness of different materials was investigated subsequently [15]. In publication [16], the thermal insulation layer on sound insulation loss factor η(-) impact was investigated as well. On the other hand, majority of the mentioned prediction models are dependent on the dynamic stiffness information obtained based on the measurement in accordance to standard EN 29052-1 [17]. The high uncertainty between dynamic stiffness measurement techniques recommended by standard EN 29052-1 [17] was declared already by [18-20]. Thanks to the strong support of the COST Action DENORMS CA15125 [21], supported by COST (European Cooperation in Science and Technology), the extensive investigation in dynamic stiffness uncertainty was performed. Partial results of the of the performed investigation during STSM supported by COST Action DENORMS CA15125 were implemented in here. In this paper the sound reduction index improvement prediction model based on [14,16] was used for comparison of spectra and single number rating of different ETICS systems with the approximately equal thermal resistance parameter. The impact of dynamic stiffness and loss factor was taken into account. The dynamic stiffness was determined by means of impact hammer excitation as well as shaker excitation (see section 3). The work was focused on the influence of the different dynamic stiffness determination impact on the sound reduction index spectra R(dB) and sound reduction index improvement ΔR_w (dB) prediction.

2. THE THEORETICAL MODEL DESCRIPTION

The analytical model for the prediction of the sound transmission index improvement, using in this paper, combines the theory presented by Weber and Cremer [5, 14, 22]. The model was subsequently modified by including terms that account for the influence of the loss factor of the damping layer [23, Eq. 1,2]. Equation 1 can be used for sound transmission index improvement spectra up to double of mass spring mass resonance frequency f_0 (Hz):

$$\Delta R_{f<2f_0} = -15log\left(\sqrt{\frac{1+\eta^2\left(\frac{f}{\frac{1}{2\pi}\sqrt{s'\left(\frac{1}{m'_1}+\frac{1}{m'_2}\right)}}\right)^2}{\eta^2\left(\frac{f}{\frac{1}{2\pi}\sqrt{s'\left(\frac{1}{m'_1}+\frac{1}{m'_2}\right)}}\right)^2+\left(1-\frac{f^2}{\left(\frac{1}{2\pi}\sqrt{s'\left(\frac{1}{m'_1}+\frac{1}{m'_2}\right)}\right)^2}\right)^2}}\right) \quad (1)$$

where m'_1 is total mass of the basic massive wall (kg.m^{-2}), m'_2 denotes the mass of the plaster layer at the thermal insulation layer (kg.m^{-2}), *s'*(N·m^{-3}) is thermal insulation dynamic stiffnessη(-) is the loss factor of thermal insulation layer and η_s(-) is the structural loss factor of the basic wall. For spectra above $2f_0$ the equation 2 can be used:

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

where f_c (Hz) is the coincidence frequency *c* (m/s) speed of the sound. Values above the coincidence frequency were considered as constant equal to value at f_c.

3. THE DYNAMIC STIFFNES AND BASIC WALL DETERMINATION

As was mentioned above, the dynamic stiffness for discussed prediction models was determined by measurements in accordance to the standard EN 29052-1 [17,18]. Measured data were subsequently used for theoretical dynamic stiffness determination in accordance to equations in [18]. The standard explains several ways how to determine the dynamic stiffness. Both techniques determines the stiffness (per unit area) as ratio of dynamic force *F* (N) perpendicularly acting on the test specimen, its surface *S* (m^2) and its resulting dynamic change in thickness of the resilient material Δd (m). However, there are several ways of specimen excitation (direction of excitation, excitation signal, excitation time etc.). This variability can bring differences to results caused by existing nonlinearities (usually in case of open cells material).

The idea of presented case study was to show the influence of the dynamic stiffness on the resulting sound insulation of the massive wall with ETICS. As explained in the standard ISO 12354-1 [24], the sound reduction index improvement can be determined as simple difference between basic wall sound reduction index and the wall after lining (or ETICS) mounting (and in other way around). To have comparison even more interesting, the situation was created, when all eight chosen thermal insulation solutions had the same thermal resistance (R_t=d/λ=3,64(m^2.K/W)). Table 1. shows the basic material properties of each thermal insulation variation used in this study. There were chosen four closed cells (expanded polystyrene (EPS), polyurethane foam (PUR), grey EPS, perforated EPS) and four open cells (variable density mineral wool) materials. Their dynamic stiffness and loss factor are shown in the table 1 as well. One can already recognize the differences of in dynamic properties, depending on the way of excitation, in case of open cells material.

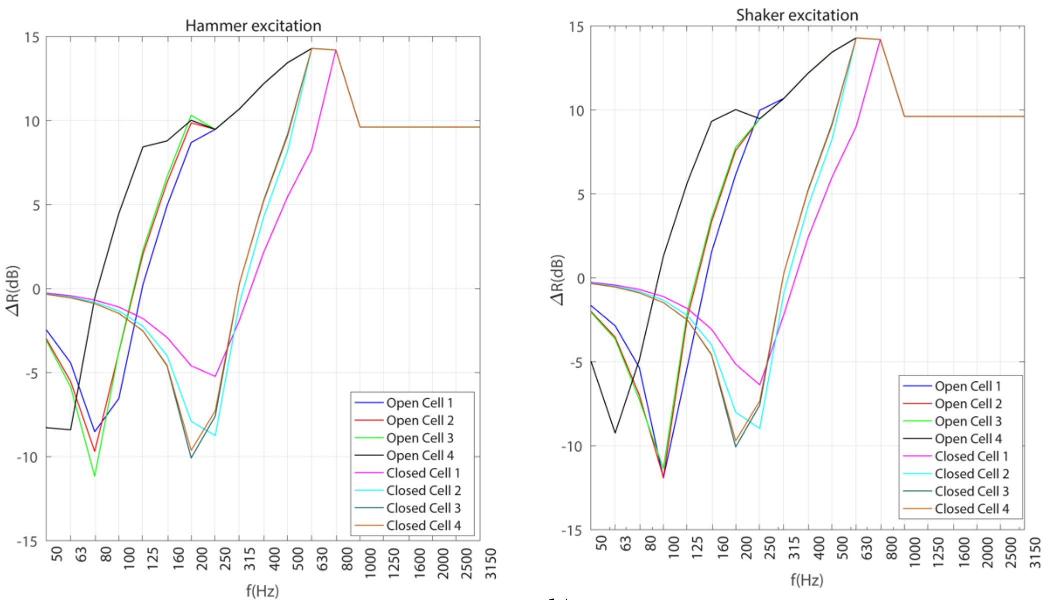
As the basic wall for the case study comparison purpose, the massive, 22 cm thick concrete wall was used. The mass of the wall per unit area was m'_1=375 kg/m^2. The mass per unit area of the plaster (at the ETICS) was m'_2=28 kg/m^2.

Table 1 Overview of thermal insulation layer material properties

				Hammer excitation		Shaker excitation	
Name	λ (W/(m.K))	ρ (kg/m^3)	d (m)	s (MN/m^3)	η (-)	s (MN/m^3)	η (-)
Open cells 1	0,036	112,8	0,13	10,4	0,065	7,3	0,187
Open cells 2	0,04	96,6	0,15	8,8	0,073	**6,2**	0,192
Open cells 3	0,035	82,5	0,13	8,6	0,078	**6,1**	0,130
Open cells 4	0,036	53,1	0,13	**4,2**	0,197	**3,1**	0,132
Closed cells 1	0,022	35,8	0,08	57,7	0,376	57,7	0,475
Closed cells 2	0,031	14,8	0,11	50,3	0,126	50,3	0,141
Closed cells 3	0,04	14,3	0,15	45,9	0,050	45,9	0,048
Closed cells 4	0,038	13,6	0,14	45,9	0,092	45,9	0,099

4. RESULTS

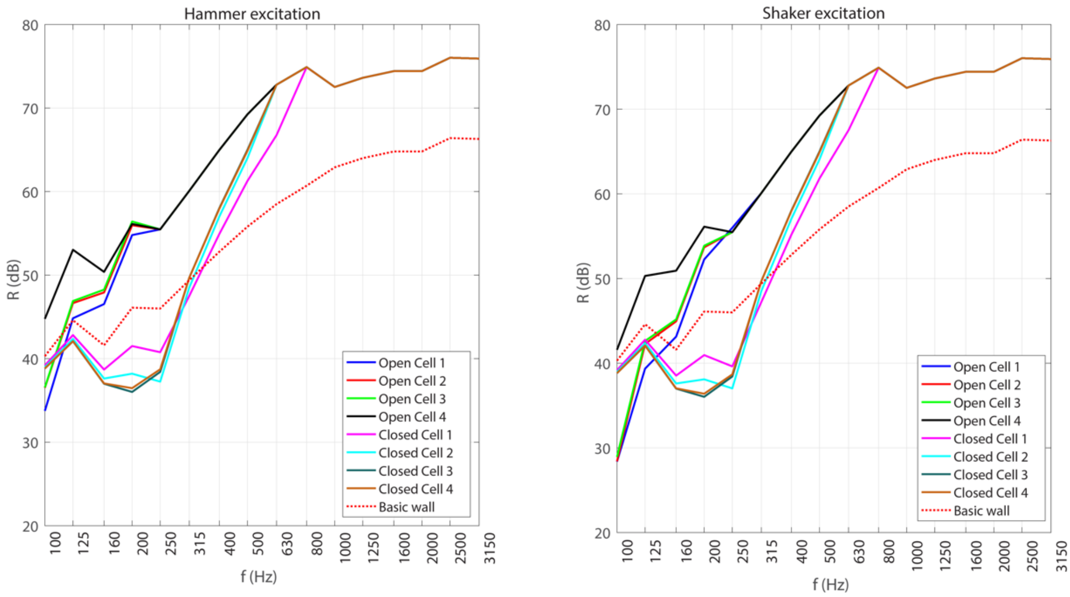
The impact of the ETICS layer on the basic wall sound insulation was determined as sound reduction index improvement ΔR (dB). The sound reduction was calculated by means of prediction model described above (Eq. 1-3). Subsequently, the resulting sound reduction index spectra R (dB) and its single number quantity R_w(dB) was derived.



a) b)

Figure 1 The sound reduction index improvement spectra. a) dynamic stiffness determined by means of the hammer excitation, b) by means of shaker excitation.

In principle, by increasing the dynamic stiffness of the thermal insulation, the resonance frequency f_0 shifts towards higher frequencies (the ETICS dynamic stiffness is dependent on the material thickness). As can be seen in table 1, in case of the "open cell" material the resulting stiffness deviated significantly (25-30% results deviation) , depending on the way of specimen excitation to determine dynamic stiffness (i.e. hammer or shaker). Results obtained by hammer excitation were giving lower resonance response (lower dynamic stiffness). The impact of this fact is shown on figures 1 and 2.



a) *b)*

Figure 2 The sound reduction index spectra. a) dynamic stiffness determined by means of the hammer excitation, b) by means of shaker excitation.

For all thermal insulation cases, by adding ETICS the sound insulation was improved for frequencies above 400Hz. However, the m-s-m resonance dip in lower frequency range negatively affected the sound insulation property (depending on the loss factor and the resonance frequency and dynamic stiffness respectively). In general, we can say that, except for one mineral wool case, the resulting sound reduction index R_w did decrease (if neglecting spectrum adaptation terms C and C_{tr}) (see Table 2). However, considering the adaptation terms C and C_{tr}, the situation is rather different (the sound insulation was improved just for cases with dynamic stiffness lower than s<6,2 (MN/m^3)). Interesting can be also to focus on the influence of differences caused by different way of stiffness determination (i.e. differences of the "open cell" material results). In case of open cell materials, the best effect has the "open cell 4", which gave sound reduction improvement index up to 7 to 10 dB (Hammer Excitation). Contrary to, the worse effect had the "open cell 1", where ΔR_w was from -9 to -4 dB (shaker excitation). As was mentioned above, closed cell materials had dynamic stiffness more than 50MN/m^3 and their results were not dependent on the way of material excitation. For closed cell materials, there was no positive improvement case in presented case study at all (negative effect up to -10 dB).

Table 2 Resulting sound reduction index and sound reduction index improvement presented in the case study (gray cells – the resulting sound reduction index was improved in comparison to the basic wall)

		R_w (dB)	C (dB)	C_{tr} (dB)	ΔR_w (dB)	ΔC (dB)	ΔC_{tr} (dB)
Shaker excitation	**Open Cell 1**	62	-9	-18	3	-7	-12
	Open Cell 2	63	-10	-19	4	-8	-13
	Open Cell 3	63	-10	-18	4	-8	-12
	Open Cell 4	69	-3	-9	10	**-1**	**-3**
Hammer excitation	**Open Cell 1**	66	-7	-16	7	**-5**	-10
	Open Cell 2	67	-5	-13	8	**-3**	**-7**
	Open Cell 3	67	-5	-12	8	**-3**	**-6**
	Open Cell 4	69	-2	-8	10	**0**	**-2**
Shaker and hammer excitation	**Closed Cell 1**	53	-6	-10	-6	-4	-4
	Closed Cell 2	54	-4	-9	-5	-2	-3
	Closed Cell 3	55	-4	-9	-4	-2	-3
	Closed Cell 4	55	-4	-9	-4	-2	-3
	Basic wall	59	-2	-6			

5. CONCLUSIONS

A case study focused on sound reduction index improvement caused by external thermal insulation composite system (ETICS) and the resulting sound reduction index prediction on a basic massive wall is presented in this contribution. Eight different thermal insulation materials were chosen, keeping the thermal resistance of the construction (facade) the same. The sound reduction index improvement was determined by means of an analytical model, using the measured dynamic stiffness and loss factor of the ETICS system. In the experiments a shaker and an impact hammer was used as excitation. Both excitation methods gave the equal results in case of "closed cell" material. However, results obtained for the "open cell" material with a lower dynamic stiffness, measurements show significant deviations for shaker or hammer excitation (25-30%). The sound reduction spectra *R* and sound reduction index R_w single number quantities were compared with a focus on the material differences and the way of stiffness determination. The negative effect of the higher material dynamic stiffness was shown. In both closed cell materials application, the sound reduction index was decreases with increasing dynamic stiffness.

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