30

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Appropriate sound insulation of facades as a measure to ensure acceptable acoustic comfort in residential buildings

APPROPRIATE SOUND INSULATION OF FACADES AS A MEASURE TO ENSURE ACCEPTABLE ACOUSTIC COMFORT IN RESIDENTIAL BUILDINGS

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SUMMARY: Wherever possible, the environment with residential buildings should be protected from the effects of noise sources by environmental noise reduction measures. If such measures cannot reduce the noise level in the environment to an acceptable level, acceptable acoustic comfort in the residential buildings shall be ensured by adequate sound insulation of the facades, which is the main topic of this paper. The paper outlines some of the criteria for providing good acoustic comfort in the residential buildings, on the basis of which the conditions and necessary measures for providing sufficient sound insulation of the facade elements are discussed. Since, in addition to the noise from the environment, the acoustic comfort in apartments is also affected by the noise from adjacent apartments in the building, the link between the sound insulation performance of facades and audibility of the speech noise form adjacent apartments is also discussed.

KEY WORDS: acoustic comfort, traffic noise, sound levels, sound insulation.

1 INTRODUCTION

One of the essential conditions for living comfort in residential buildings is acoustic comfort, which means providing such acoustic conditions in living spaces that will allow residents to sleep, rest, work and do other activities without interruption. This goal can be achieved by reducing the noise levels to such an extent that they do not exceed values which still provide adequate acoustic comfort. It can be done either by reducing the noise emission of the sound sources, by reducing the impact of sound propagation from the noise sources toward the living spaces of dwellings or by providing adequate sound insulation of dwellings.This contribution is focused on the protection of residential spaces against environmental noise by providing sufficient sound insulation performance of the facades.

It is well known that the sound insulation performance depends on the spectrum of noise which is to be reduced and that consequently the sound insulation performance of the façade is not the same for all environmental noise sources. In this respect the discussion in the following sections is focused on the sound insulation performance of the façade against the traffic noise which is recognized as a typical and the most relevant environmental noise source. Namely, recent research show that more than 30% of EU citizens are exposed to road traffic noise levels above that viewed acceptable by the World Health Organisation (WHO).

The positive side of good sound insulation performance of the façade is the noise level reduction inside the building, but it should not be forgoten that this leads to an increase in sensitivity to noise from adjacent spaces in the building. In this respect the last part of this contribution is focused on a typical example of this kind, namely on the audibility of the speech from the adjacent apartments in the building.

2 MEASURES TO REDUCE THE IMPACT OF ENVIRONMENTAL NOISE SOURCES ON HOUSING

To reduce the impact of the environmental noise sources, such as: traffic, industry, etc., on the residents in the residential buildings the following noise reduction measures are available:

- measures at the noise source,
- measures along the path of noise propagation and
- measures at the noise receiver.

In the case of traffic noise for example, typical noise reduction measure at the source is the use of the “quiet" road surfaces to reduce the tyre-road noise emission, which is the most important source of the traffic noise emission. To reduce the traffic noise propagation the noise barriers are used and to reduce the impact of the traffic noise on the indoor noise in residential buildings the improvement of the sound insulation performance of the façade is necessary.

For measures at the noise source and along the path of noise propagation the expression “active noise reduction measures” is usually used, while for the measures at the noise receiver by improving of the sound insulation performance of the façade, the expression “passive noise reduction measures” is usually used.

Closer to the noise source are the sound reduction measures implemented more effective they are, because the teritory, protected by such measures, is larger in such cases. That is the reason why the active noise reduction measures have advantage compared to the passive noise reduction measures. Therefore, wherever possible, the environment in which residential buildings are located should be protected from the effects of noise sources primarily by the active noise reduction measures. But in spite of the advantage of the active noise reduction it is sometimes inevitable to use passive noise reduction measures by improving sound insulation performance of the façades. It is typically inevitable in the case of the sound insulation of upper flats of the high residential buildings near high-trafficked roads.

To ensure a good acoustic comfort in the building it is necessary to ensure that the level of the indoor noise due to the traffic should not be to high. At least in some Central European countries, including Slovenia, the mandatory limit indoor noise level is nowhere below 30 dBA at the moment, which is acceptable but it does not provide good acoustic comfort [2,3,4,5]. Namely, recent researches show that for a good acoustic comfort the limit noise level should not exceed 25 dBA [6,7].

3 SOUND INSULATION PERFORMANCE OF FACADES AND ITS INFLUENCE ON THE INDOOR NOISE LEVEL

The sound insulation performance of façade elements and façades is usually described by the sound reduction index R' [8]. It can be evaluated from:

$$R' = L_{outdoor,S} - L_{indoor} + 10.log(S.T/0,16.V) - 3dB \qquad (1)$$

where

$L_{outdoor,S}$ is the average sound pressure level on the outside surface of the façade, including the reflected effects from the façade (dB),
L_{indoor} is the average indoor sound pressure level in the receiving room (dB),
S is the total area of the façade as seen from the inside (m^2),
V is the volume of the receiving room (m^3)
T is the reverberation time of the receiving room (≈ 0,5s $=T_0$ for furnished room).

The reverberation time is by definition the time, required for the sound level in the room to decrease for 60 dB after turning off the loudspeaker.

However, the recent findings show [9] that the standard level difference $D_{2m,nT}$ is a quantity which more appropriately reflects the human perceiving of the sound insulation performance of the façade than the sound reduction index. It can be evaluated from [8]:

$$D_{2m,nT} = L_{outdoor,2m} - L_{indoor} + 10.\log(T/T_0) \qquad (2)$$

where

$L_{outdoor,2m}$ is the average sound pressure level at 2m in front of the façade (dB),
L_{indoor} is the average indoor sound pressure level in the receiving room (dB),
T is the reverberation time of the receiving room (≈ 0,5s for furnished room),
T_0 is the reference reverberation time = 0,5s.

Both quantities R' and $D_{2m,nT}$ depend on the frequency of sound, so the sound insulation performance has to be determined for each frequency band within the relevant frequency region, usually between 100 Hz and 3150 Hz. Such a way of describing the sound insulation characteristics is obviously pretty cumbersome and that is why the procedure was established to evaluate the overall sound insulation performance with a single numbers R'_w (weighted sound reduction index) or $D_{2m,nT,w}$ (weighted standard level difference) [8].

The ultimate goal in expressing sound insulation performance is to determine the value that will represent the difference between the outdoor and indoor sound levels, accommodated to human perception. For that reason the spectral adaptation terms were introduced [8], C_{tr} for traffic noise and C for other types of noise, which have to be added to the single numbers R'_w or $D_{2m,nT,w}$ to get the abovementioned level difference:

$R'_w + C_{tr} = R'_{Atr}$ and $R'_w + C = R'_A$

$D_{2m,nT,w} + C_{tr} = D_{2m,nT,Atr}$ and $D_{2m,nT,w} + C = D_{2m,nT,A}$

As a typical practical example let us take S = 4 m x 2,5 m = 10 m^2 for a typical surface of the façade and V = 3 m x 4 m x 2,5 m = 30 m^3 for a typical room volume. Standard reverberation time of the room is 0,5 s (furnished room). The façade is presumed to be plain. In such a case R' and $D_{2m,nT}$ are approximately equal. For this typical example, we will hereafter express the sound insulation performance mainly by the weighted sound reduction indices R'_w , R'_{Atr} and R'_A.

Based on above mentioned assumptions the indoor sound pressure level, produced by the road traffic noise and accommodated to human perception of noise, is given by:

$$L_{indoor} \approx L_{outdoor,2m} - (R'_w + C_{tr}) \qquad \text{dBA} \qquad (3)$$

where

L_{indoor} is the average indoor sound pressure level in the receiving room (dBA),
$L_{outdoor,2m}$ is the average sound pressure level at 2m in front of the façade (dBA),
$(R'_w + C_{tr}) =$
$= R'_{Atr,facade}$ is the weighted sound reduction index of façade, spectrally adapted to the traffic noise and accommodated to human perception of noise (dBA).

Based on equation (3) the required sound insulation performance of the façade for different outdoor traffic noise levels and for different indoor noise level limits is presented in Figure 1. The values of $R'_{Atr,façade}$ are calculated for the abovementioned characteristic dimensions and furnishing of the room. The outdoor noise levels in Figure 1 are the levels without reflection effects of sound from the façade (so called free-field noise levels, usually determined by the environmental noise modelling).

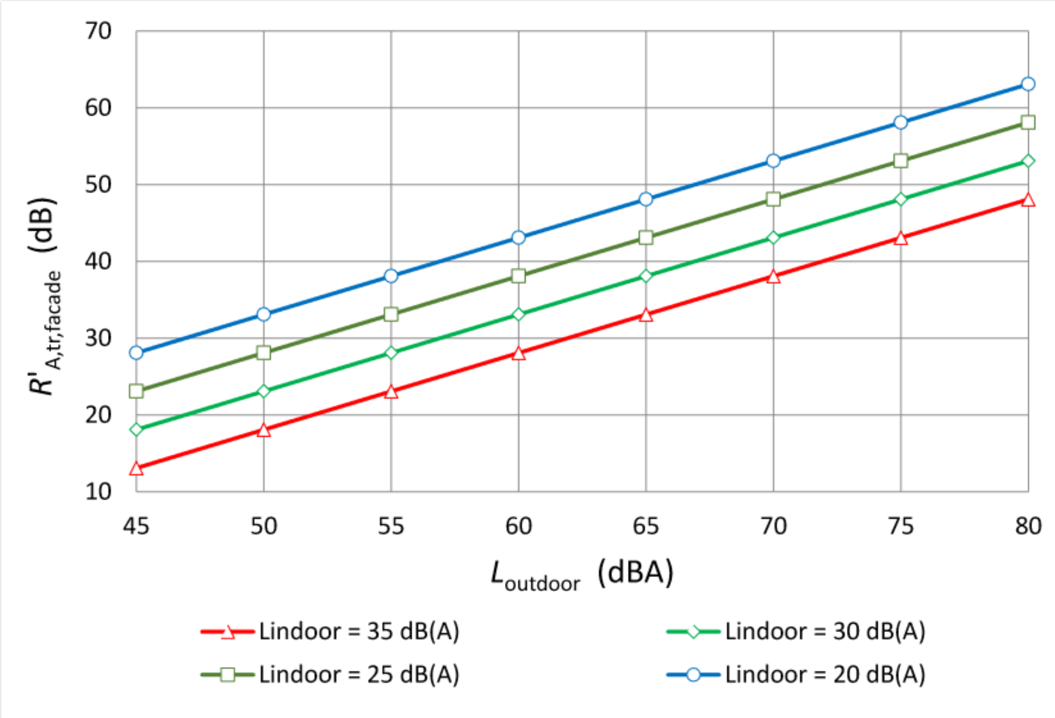

Figure 1: Required sound insulation performance of the façade for different outdoor noise levels and for different indoor noise level limits - calculation example for the characteristic dimensions and furnishing of the room

Overall sound insulation performance of the façade depends on the sound insulation performance of the wall and on the sound insulation performance of the glazed part of the façade. An example of sound insulation performance of the typical 10 m^2 large façade with the 1,4 m wide and 1,4 m high window is presented in Figure 2.

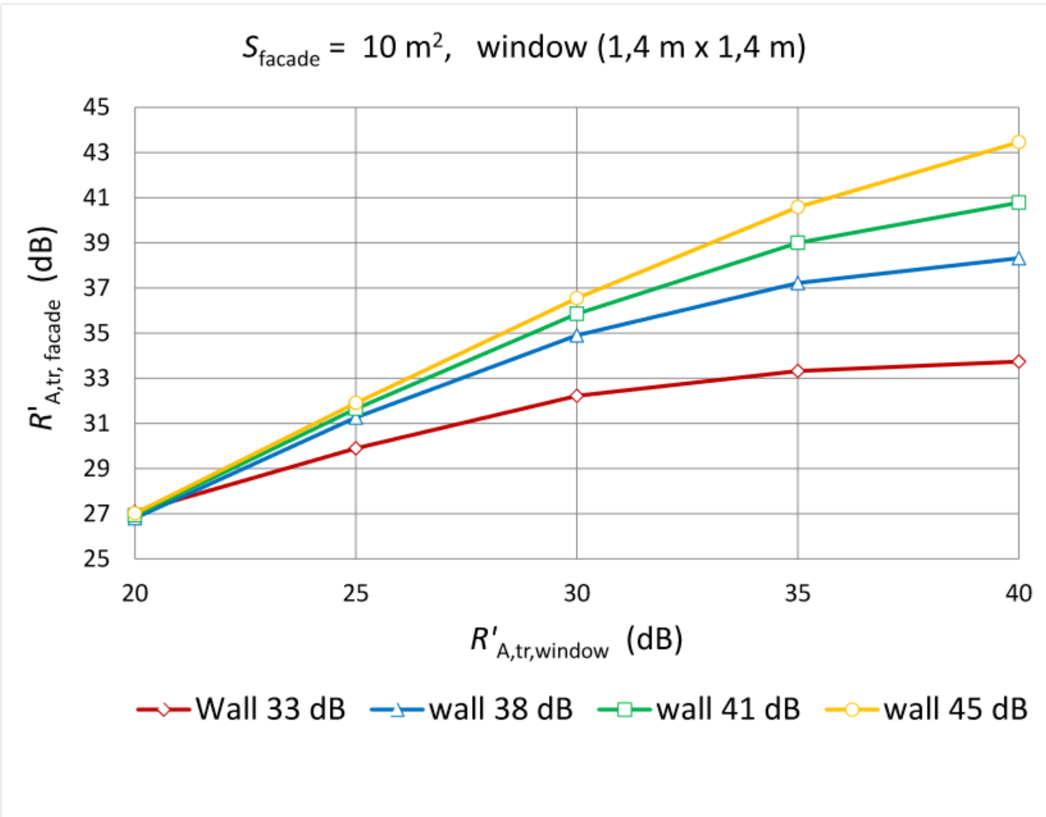

Figure 2: Sound insulation performance of the façade for different sound insulation performances of the window and of the wall - calculation example for the characteristic dimensions and furnishing of the room

Typical sound reduction index $R'_{Atr,window}$ of newly installed windows in Slovenia (not older than app. 10 years, with the triple glazing 4-12-4-12-4 or double glazing 4-16-8) is somewhat around 32 dB [10]. For a common case where the façade wall is masonry wall with the external thermal insulation lining (ETICS), the expected sound reduction index R'_{Atr} of the wall is around 45 dB [11]. In Figure 2 it can be seen that the combination of such a window with a typical façade wall with R'_{Atr} around 45 dB gives the overall sound reduction index of the façade $R'_{Atr,façade}$ around 38 dB. In Slovenia the prescribed indoor noise level limit in dwellings in the day time when the road traffic is the loudest is 35 dBA. Taking this into account it can be seen in Figure 1 that typical sound reduction index $R'_{Atr,façade}$ of the façade 38 dB is too low for the regions where the outdoor level exceeds 70 dBA, which means for the regions near high-trafficked roads. It is necessary to have in mind that the indoor noise limit 35 dBA does not provide a good acoustic comfort in dwellings so therefore the limit value should be lower. As a relevant indoor noise level for dwellings in a typical residential area the indoor level of maximum 25 dBA could be taken [6,7]. In such a case the typical sound insulation performance of the façade with the newly installed windows in Slovenia would be appropriate only for the regions where the outdoor noise level does not exceed 60 dBA which is a typical noise level for the regions near the roads with little traffic.

We presume now, as an example, that the sound reduction index of the window $R'_{Atr,window}$ would be 40 dB, which is a pretty high value for a window. From the graph in Figure 2 it can be seen that the overall sound reduction index of the façade $R'_{Atr,facade}$ would be approximately 43 dB in this case. The graph in Figure 1 further shows that for this value of the sound reduction index the limit outdoor noise (without reflections from the façade) should not exceed approximatelly 75 dBA for the case when the limit indoor noise level is taken to be 35 dBA. The noise level 75 dBA is typical for the regions near the high-trafficked roads. But in the case the indoor noise limit is lower, for example 25 dBA which is much more acceptable than 35 dBA, than the outdoor noise level should not exceed approximatelly 65 dBA which is a typical noise level for the regions near the roads with moderate traffic.

The above discussion shows that for providing a good acoustic comfort in dwellings the very good sound insulation performance of the façade is needed, especially in the regions near the high-trafficked roads. This is not so easy to achieve, especially due to the combined effect of the spectral characteristics of the road traffic noise and the unfavorable sound insulation characteristics of the masonry wall with the external thermal insulation lining (ETICS) in the low frequency region below app. 315 Hz [12]. All these lead to the rather low sound insulation performance of the façade wall with the typical sound reduction index R'_{Atr} around 45 dB. As already mentioned, to provide an acceptable acoustic comfort in dwellings the indoor noise should not exceed the noise level of around 25 dBA. It follows that such sound reduction index of the wall in combination with the sound reduction index of the window $R'_{Atr,window}$ (which rarly exceed the value of 45 dB) cannot provide sufficient sound insulation against the traffic noise in the noisy regions where the outdoor noise level exceed 70 dBA (Figure 1).

In addition to the abovementioned facts it is necessary to take into account that the sound insulation of the façade is of course provided only with the windows closed, which is not desirable from the point of view of living comfort. In addition, requiring the windows to stay closed requires different type of room ventilation, which may affect the sound insulation of facade. Therefore, caution should be exercised when installing ventilation devices (e.g. ventilation ducts in the facade) which, if not properly acoustically designed, can significantly impair the overall sound insulation of the facade. It is also important not to forget to mention that the sound insulation of the facade can also be significantly reduced due to the transmission of sound through improperly acoustically designed shutter boxes.

The conclusion is that primarily the whole area with residential buildings should be protected wherever it is possible. In that way a good acoustic comfort in the buildings is consequently also provided, without the restriction that windows have to be closed. Passive noise reduction measures with the adequate sound insulation performance of the façade should therefore be used only as an additional measure and only when they are inevitable (e.g. too high residential buildings located near high-traffic roads).

4 THE IMPACT OF INCREASING THE SOUND INSULATION OF A FAÇADE ON THE AUDIBILITY OF SPEECH FROM AN ADJACENT APARTMENTS

The environmental noise is of course not the only noise to which the people inside the residential building are exposed. They are also exposed to the noise produced inside the building, for example to the noise from adjacent apartments, like speech, TV, walking, moving of chairs etc., and to the noise of service equipment. In the case of poor sound insulation of the facade, the influence of the outdoor noise on the indoor noise level mostly prevails compared to the effect of noise, generated by the noise sources inside the building. In such a case the environmental noise masks the impact of the noise sources in the building. But there is a completely different situation when the sound insulation of the facade is good. In such a case the sensitivity to noise generated by the noise sources inside the building becomes more highlighted, which means that it is necessary to provide better sound insulation against the noise of that sources [13,14,15]. Let us take as an example the audibility of speech from the adjacent apartment (Figure 3).

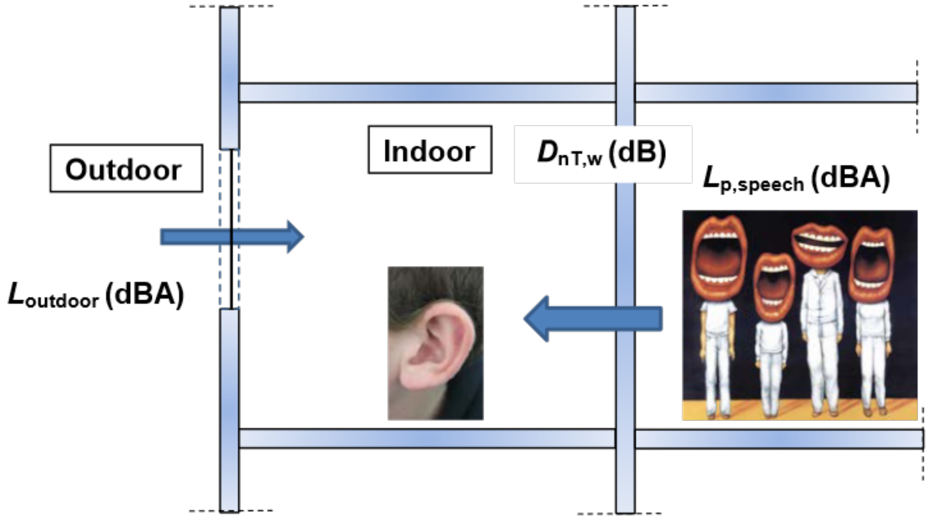

Figure 3: Audibility of speech in the adjacent room as a function of sound insulation performance $D_{nT,w}$ and the indoor noise level, produced by the environmental noise

Tables 1 and 2 show the speech audibility and intelligibility dependence on the sound insulation against adjacent room and on the indoor noise, produced by the environmental noise [15]. Sound insulation performance of the wall against adjacent room is described by the weighted standard level difference $D_{nT,w}$ in this case, like in the reference [15].

Table 1: Audibility of loud speech from adjacent room [15]

Sound insulation against adjacent room	Indoor noise, produced by the environmental noise (dBA)			
	35	30	25	20
$D_{nT,w}$ (dB)	**Loud speech** from adjacent room (L_p = 75 dBA) is			
62	**not audible**	**not audible**	**not intelligible, barely audible**	**not intelligible**
57	not audible	not intelligible, barely audible	not intelligible	still intelligible
52	**not intelligible, barely audible**	**not intelligible**	**still intelligible**	**well intelligible**
46	not intelligible	still intelligible	well intelligible	well intelligible

Table 2: Audibility of normal speech from adjacent room [15]

Sound insulation against adjacent room	Indoor noise, produced by the environmental noise			
	dBA			
	35	30	25	20
$D_{nT,w}$	**Normal speech** from adjacent room (L_p = 68 dBA) is			
dB				
62	**Not audible**	**Not audible**	**Not audible**	**Not audible**
57	Not audible	Not audible	Not audible	Not intelligible, barely audible
52	**Not audible**	**Not audible**	**Not intelligible, barely audible**	**Not intelligible, but still audible**
46	Not intelligible, barely audible	Not intelligible	Not intelligible, but still audible	Well intelligible

As mentioned before, for the geometry and standard reverberation time of a typical room it holds that $D_{nT,w} \approx R'_w$. The weighted sound reduction index for the wall between adjacent appartments, prescribed by the slovenian regulation [2], is 52 dB. In Tables 1 and 2, respectively, it can be seen that for this value in combination with the indoor noise limit 25 dBA the loud speech from the adjacent room is still intelligible, and the normal speech is barely audible and not intelligible. The value 52 dB is a minimum requirement and it is obviously not adequate for the good acoustic comfort. From Tables 1 and 2 it can also be seen that to provide a good acoustic comfort the value $D_{nT,w}$ should be at least 62 dB which usually entails radical construction measures to ensure such sound insulation performance which at the moment is still not a standard in the majority of european countries [16].

5 CONCLUSIONS

For protection against road traffic noise, active noise control measures at the source or on the path of noise propagation should be taken wherever possible. In such a way not just apartments are protected, but also the entire area in which residential buildings are located. Only in cases where these measures are not expected to be effective, e.g. in the cases of high-rise residential buildings near roads, the upper floors should be protected by passive measures by ensuring adequate sound insulation of the facades.

It turns out that, in order to provide adequate acoustic comfort in the building, it is necessary to provide relatively good sound insulation performance of the facade, especially near high-trafficked roads. By using the materials of the facade elements and facades which are common in newly built buildings and at adaptations of older buildings (eg ETICS) this is usually not guaranteed. In addition, care must be taken when using the ventilation systems in facades and by installation of shutter-boxes. If the sound insulation of these elements is inadequate, the sound insulation of the whole facade can be significantly degraded.

Last but not least it should be noted that by improving the sound insulation performance of the façade the sensitivity to noise, generated by the noise sources inside the building becomes more highlighted. For that reason good sound insulation performance of the façade shall always been linked to the good sound insulation performance of the internal partitions of the building. In the case of speech for example, the weighted standard level difference $D_{nT,w}$ of the partition should be at least 62 dB to ensure the good acoustic comfort in dwellings where the noise level is around 25 dBA. This usually entails radical construction measures to ensure such sound insulation performance which at the moment is still not the standard in the majority of european countries. It means that there is still a lot to do in this respect, with intention to raise the level of the noise control enough to ensure the desired acoustic comfort in dwellings.

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