Masking effect of HVAC noise on walking sounds on concrete floors

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ABSTRACT

Background noise masks living sounds in apartment buildings. Depending on the sound insulation properties of the structures of the apartments, background noise affects the audibility of the perceived airborne and impact sounds from neighboring dwellings. This preliminary study focused on the masking effect of the background noise generated by HVAC systems on the impact sounds generated by walking on concrete floors. The study was carried out by determining the signal-to-noise ratios of walk induced sound levels on the concrete floors and measured background noise levels. The walking sounds were generated by walking with socks and shoes on nine concrete floors, and the sound pressure levels were measured in a receiving room below the floors. These walking sounds were compared with background noise levels which consisted of the results collected in 210 measurements in Finnish apartment buildings. The results of the study indicate that the background noise masks sound from walking with socks and shoes differently.

1. INTRODUCTION

Living sounds comprise both airborne and impact sounds caused by human activities such as talking, music, children playing, and walking. A subjective perception of sound insulation against living sounds between neighboring dwellings is affected by the level and the character of the sounds as well as the sound insulation properties of the structures between rooms. Furthermore, the perception of sound insulation depends on the background noise of the receiving room due to sound masking effect [1]. In apartment buildings, the background noise usually occurs due to environmental sound sources, such as traffic, and HVAC systems.

In case of airborne sound insulation, it has long been recognized that the masking effect is an important factor for the perceived sound insulation [2–4]. Increasing background noise in buildings, leads to improved speech privacy between rooms [5]. The background noise also affects the perception of drum sounds, i.e., the walking sounds generated in the same room with listeners [6].

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Furthermore, the masking effect is a relevant issue for the perceived impact sound insulation, however, at low-frequencies, it is possible that the background noise cannot affect the audibility of the walking induced impact sounds [7, 8].

The purpose of this preliminary study was to investigate the masking effect of HVAC noise on walking sounds on concrete floors. This study combines data from two studies carried out in 2012. First, the data includes laboratory measurements of walk induced impact sounds on nine concrete floors. Secondly, field measurement data from background noise level spectra measured in 210 Finnish apartment rooms have been used. To study the masking effect of the HVAC noise, signal-to-noise ratios (SNR) of walk induced sound levels and background noise were determined.

2. MATERIALS AND METHODS

2.1. Walking sounds on concrete floors

The experiments were carried out at a laboratory, where the bearing floor structure was a 265 mm thick concrete hollow core slab (400 kg/m^2) [9]. The floor, on which the walking tests occurred, lied between vertically adjacent source and receiving rooms. The measured reverberation times of the receiving room corresponded well with those of typical furnished rooms in Finnish dwellings [10]. Therefore, the sound spectra measured in the receiving room can be considered to correspond well with the typical spectra in residential dwellings.

In addition to the bare floor (F1), the experiments were carried out on eight covered floors (F2–F9) to cover the typical impact sound insulation spectra found in dwellings. The size of the floor covering was 3,0 x 4,0 m^2 in each case. Table 1 shows the layers of floor surface structures for all the studied floors, as well as the weighted reduction of impact sound pressure levels ΔL_w for floor coverings, and dynamic stiffnesses s' for mineral wools. Furthermore, the measured single-number quantities (SNQ) $L'_{n,w}$ and $L'_{n,w} + C_{I,50\text{-}2500}$ have been shown for each floor in Table 1. These standard measurements were carried out by using a tapping machine. Note that in case of negative spectrum adaptation terms $C_{I,50\text{-}2500}$, the value of the term in the sum $L'_{n,w} + C_{I,50\text{-}2500}$ was 0 dB.

Table 1: The structural layers of floor coverings on the nine studied floors, and SNQs of the floors.

Denotation	Structural layers of floor covering	$L'_{n,w}$	$L'_{n,w} + C_{I,50–2500}$
Floor F1	No covering	80 dB	80 dB
Floor F2	Cushion vinyl, ΔL_w = 2 dB	78 dB	78 dB
Floor F3	Cushion vinyl, ΔL_w = 21 dB	59 dB	59 dB
Floor F4	Multilayer parquet and soft underlay, ΔL_w = 20 dB	60 dB	60 dB
Floor F5	Wall-to-wall carpet, ΔL_w = 21 dB	59 dB	59 dB
Floor F6	Wall-to-wall carpet, ΔL_w = 37 dB	43 dB	47 dB
Floor F7	Multilayer parquet 14 mm Soft underlay 2 x plasterboard 15 mm (30 kg/m^2) Mineral wool 13 mm, s' = 16,1 MN/m^3	51 dB	56 dB
Floor F8	Multilayer parquet 14 mm Soft underlay 2 x plasterboard 15 mm (30 kg/m^2) Mineral wool 50 mm, s' = 11,5 MN/m^3	44 dB	53 dB
Floor F9	Multilayer parquet 14 mm Soft underlay 4 x plasterboard 15 mm (60 kg/m^2) Mineral wool 50 mm, s' = 11,5 MN/m^3	42 dB	48 dB

The present standardized SNQs expect that the main impact sound source is walking with hard-heeled shoes. This sound type does not necessarily reflect the most typical impact sounds in all countries [11–14]. Therefore, three male walkers W1, W2 and W3 (Table 2) wore socks, soft-heeled shoes, and hard-heeled shoes in the walking sound experiments. The same personal footwear was used through the test series. Walkers walked along a predetermined rectangular and an hourglass-shaped track on each floor for 40 seconds. During the walk, the SPLs were recorded in the receiving room at two microphone positions as a function of time with time weighting FAST. Measurements were performed twice.

The measured SPLs were background-noise corrected and spectra of momentary maxima for individual steps were sought from the A-weighted SPL $L_{A,F}(t)$. Typical number of maxima were 50-60 per each measurement. Considering the repetition of the measurements and the two measurement positions, sample of momentary maxima for each walking consisted typically of 200–250 spectra (of individual steps). From these maxima, an energetic average spectrum was calculated for each experiment to present an average walking SPL for each measured case (see Figure 1). The generation of the walking sound and calculation of the spectra have been described in more detail in an earlier article [9]. The measurement data has been described as a whole in [15].

Table 2: Dimensional analysis of the walkers. The shoe sizes correspond to the European measures.

Walker	**Age**	**Mass**	**Height**	**Shoe size**
W1	22	86 kg	188 cm	46
W2	40	125 kg	191 cm	44
W3	23	91 kg	183 cm	42

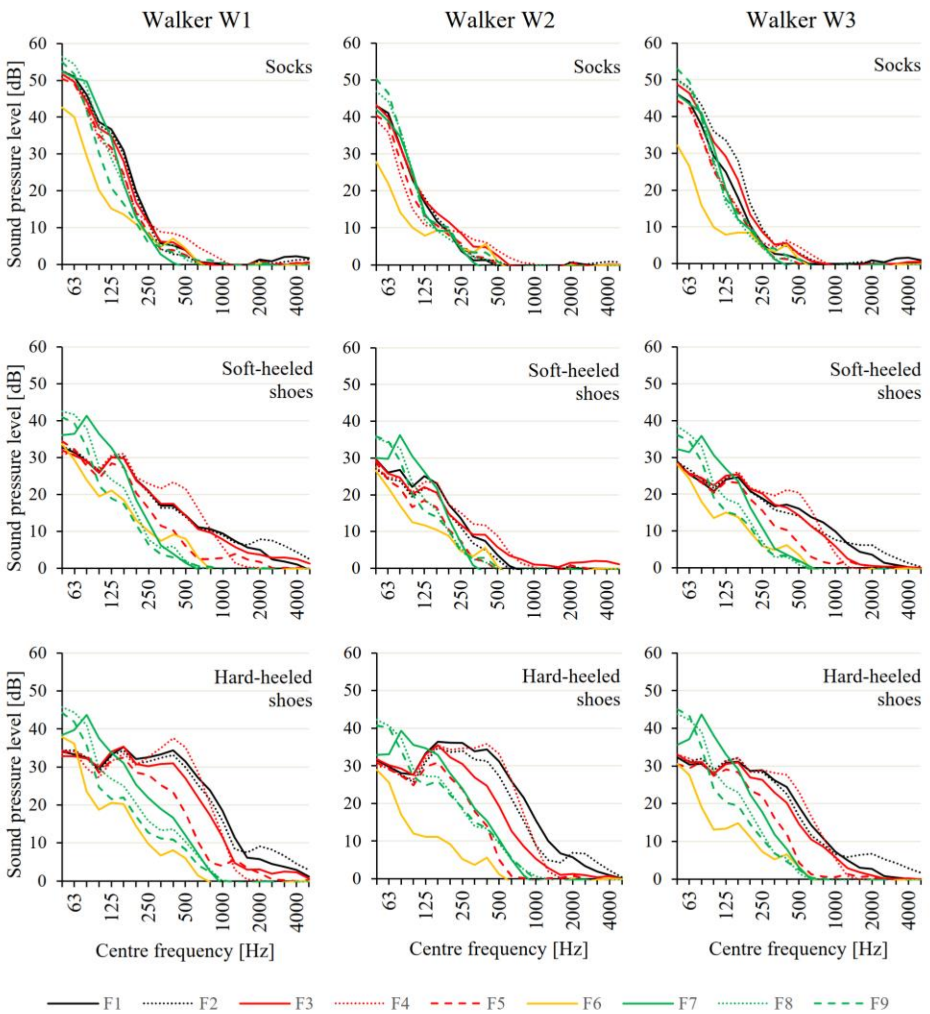

Figure 1: Energetic averages of walking sound spectra based on momentary maxima of $L_{A,F}(t)$ at 1/3-octave bands in the frequency range 50 to 5000 Hz [9].

2.2. Background noise generated by HVAC systems

Data for the background noise considered in this paper originates from the study [16, 17]. The data was collected from airborne and impact sound insulation measurements performed in furnished Finnish apartment rooms during the years 2009–2013. In total, 210 results for equivalent SPL describing the background noise generated by HVAC systems were received from the study. The measurements were carried out in buildings finished between the years 1885 and 2013, and the room volume varied from 14 to 220 m^3. Figure 2 depicts the whole measurement data for the background noise, as well as mean, median, upper and lower quartiles of the SPLs [9].

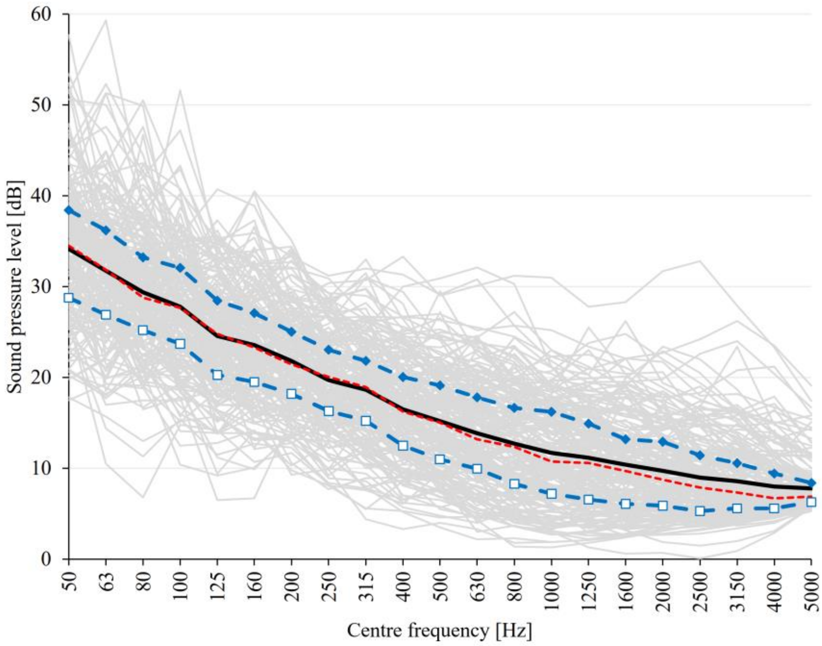

Figure 2: Background noise levels generated by HVAC systems in Finnish dwellings at 1/3-octave bands (grey lines). Continuous black line depicts the mean value. Upper and lower quartile have been shown with dashed blue lines and marked with blue diamonds and white rectangles, respectively; median value of the results has been illustrated with dashed red line. [16, 17]

2.3. Signal-to-noise ratio of walking sounds and background noise

Audibility of walking sounds was assessed by determining the SNRs of walking sounds and background noise for each 1/3-octave band b as follows:

$$SNR = S_b - N_b, \tag{1}$$

where S_b is the walking induced SPL, and N_b denotes the SPL of the background noise generated by HVAC systems. Calculation of SNR was carried out for each energetic average of walking sound spectra (see Figure 1) and individual SPLs for background noise (see Figure 2, grey lines).

3. RESULTS AND DISCUSSION

Results for the SNRs of the walk induced impact sounds and background noise have been shown in Figure 3 for walking with socks, soft-heeled shoes, and hard-heeled shoes on each of floor. As walker W1 appeared to be the loudest of the three (see Figure 1), only results of W1 will be shown. Figure 3 depicts the percentages of SNRs larger or equal to -15, -10, -5, 0, 5, 10, and 15 dB (from top to bottom in each subplot) in 1/3-octave bands in the frequency range 50 to 5000 Hz. Thus, the higher percentage of the high values of SNR, the better the audibility of the walking sound in the corresponding frequency band is. In other words, the audibility of the walking sound increases when the lowest red curves reach higher values. The thicker black lines in the figure denote SNR = 0 dB level.

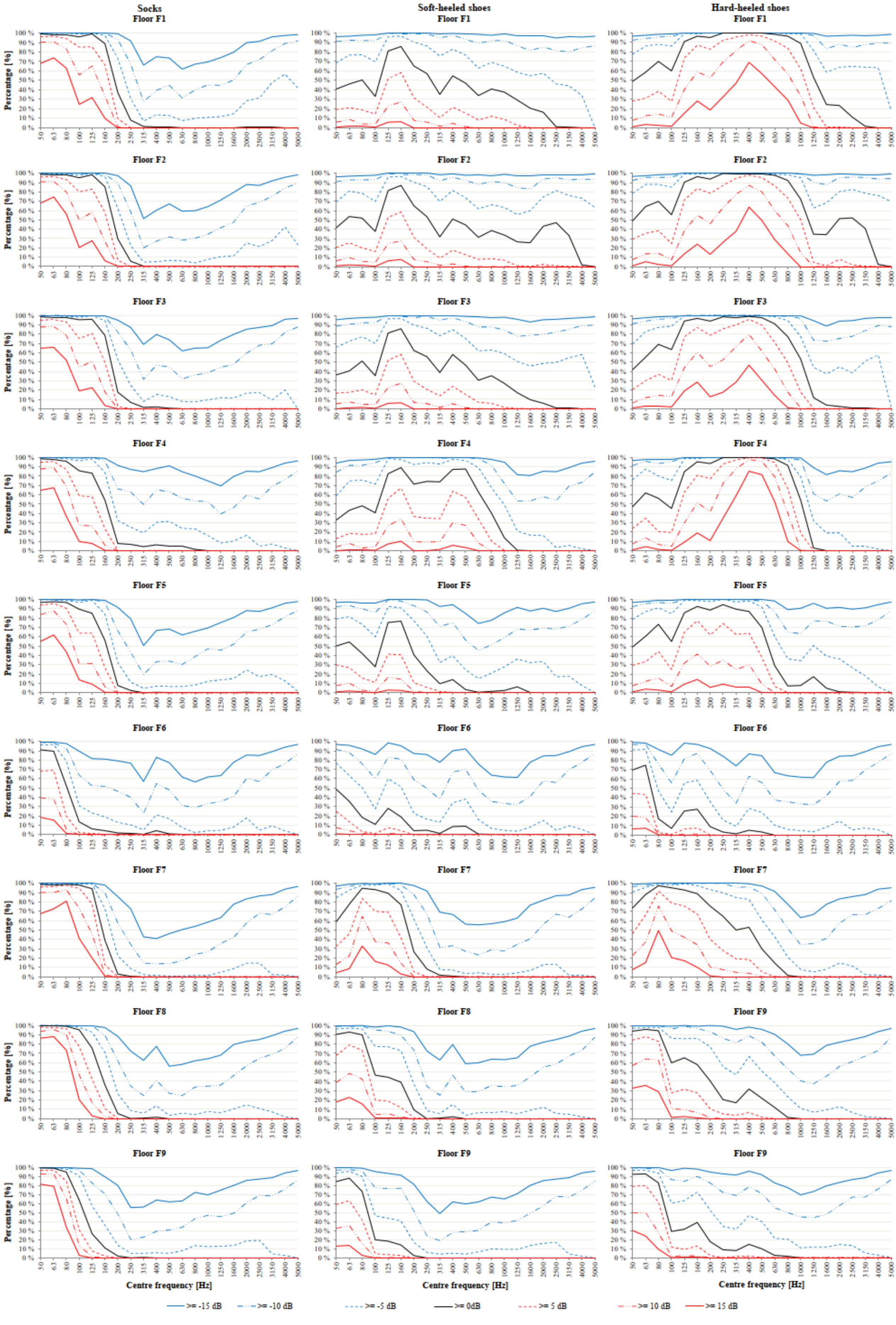

Figure 3: Percentages of SNRs of walk induced SPLs and background noise levels from HVAC systems. From left column to right: W1 walking with socks, soft-heeled and hard-heeled shoes.

In case of walking with socks, the SNR curves (as well as SPLs generated by walking, see Figure 1) were rather consistent regardless of floor. The SNR got high levels in the low-frequencies and low levels above 200 Hz. At this latter frequency range, the walk induced SPLs were near 0 dB (see Figure 1), thus the walking sound would hardly be audible even without the masking effect of the background noise. In the low-frequency range, the SNRs are even above 15 dB for most of the floors. The greatest values of SNRs occur with the floating floors F7–F9 around the resonance frequencies of the floating structures. Only the floor F6 showed lower levels of SNRs in low frequencies in comparison with the other floors. The results imply that the background noise is not masking the walking sound in low frequencies, as previously noted by [7, 8].

Walking with shoes caused the SNRs above and equal to 0 dB to spread to higher frequencies especially in case of the bare and lightly covered floors F1–F5. For these floors, the SNR curves seemed to differ greatly from walking with socks. Walking with hard-heeled shoes caused even a peak to SNR values around 400 Hz for the floors F1–F4. Hence, it is likely that there is no background noise capable of masking these walk induced sounds in the mid-frequencies in typical dwellings. This gives a possible explanation to the question why impact sounds generated by walking with hard-heeled shoes are regarded annoying. In case of the floating floors F7–F9 and the floor F6, the SNR curves resemble the ones gained for walking with socks but with a spread of values from 0 to 15 dB to the larger frequencies. Again, the SNRs levels are at the highest around the resonance frequency of the floating floors.

According to the authors' knowledge, the minimum SNR level required to reach satisfactory subjective impact sound insulation against the living sounds caused by walking is not known. To reach very low background noise levels generated by the HVAC systems is often expensive which adds costs to building projects. Background noise can obviously, at least partly, mask the walking sounds at low and mid-frequencies, which is likely to affect the perceived impact sound insulation. For these reasons, the masking effect of background noise on living impact sounds should be further studied from the point of view of audibility and annoyance. However, it can be a rather demanding, if not impossible, task to design HVAC systems to produce an exact type of sound to mask walking sounds similarly in every apartment of a building.

4. CONCLUSIONS

This preliminary study shows that background noise generated by HVAC systems in dwellings cannot mask impact sounds generated by walking with socks in the low frequencies below 200 Hz. Moreover, the masking effect is unlikely in case of walking with shoes in the low- and mid-frequency range from 50–1000 Hz. On the bare and lightly covered floors F1–F4, walking with hard-heeled shoes caused comparatively high SPLs around 400 Hz which the typical HVAC noise cannot mask. The results of this study imply that the masking effect regarding walking sounds with socks might be worth to study further. However, it might be possible that in all cases suitable masking sounds cannot be generated by HVAC systems only.

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