CHALMERS

Suggested facade cases for study of sound insulation considering wall, window and air intake

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1. Introduction

In the project *Quieter Transport for More Efficient Distribution* we are investigating sounds from noise improved heavy-duty road vehicles and their indoor impact in urban environments, whereby it is of interest to define a relevant set of facade cases. As input we have reduction indices in third-octave bands 25–20 000 Hz, delivered from acoustic consultant *Simmons akustik & utveckling ab*, for a set of facade elements that were selected with objectives of both frequency of use and of spread in sound reduction. The third-octave band reduction indices for three facade walls, four windows and two air intakes are listed in the appended report (in Swedish). From these facade elements a set of six cases are suggested for use within the project.

2. Suggested cases

The set of facade walls consists of (1) an ordinary timber frame type, (2) a new steel frame type (i.e. a lightweight wall) and (3) a new concrete wall type. For the set of window examples we have an old window of (1) a normal type and of (2) an improved type, (3) a new ordinary window and (4) a new noise proof window. The air intakes are of (1) an ordinary type and (2) a noise proof type. For all facade cases the same room is assumed, a bedroom type of room with a 12 m^2 floor area and a 10 m^2 facade area facing the road. The reverberation time is assumed to be 0.5 s for all frequencies. Concerning the individual areas of the facade elements, the old windows are 1.9 m^2 whereas the new windows are 1.5 m^2 in size, and the air intakes use a 10 m^2 reference area.

Since the project mainly concerns sounds from trucks, we here make use of the C_{tr} spectrum (standardized emission spectrum for heavy road vehicles [1]) as an outdoor spectrum to illustrate the indoor levels, after extending the domain from the third-octaves 50–5000 Hz to the 25–20 000 Hz range used here. The A-weighted spectrum used here is shown in Figure 1 (and listed in Table 1).

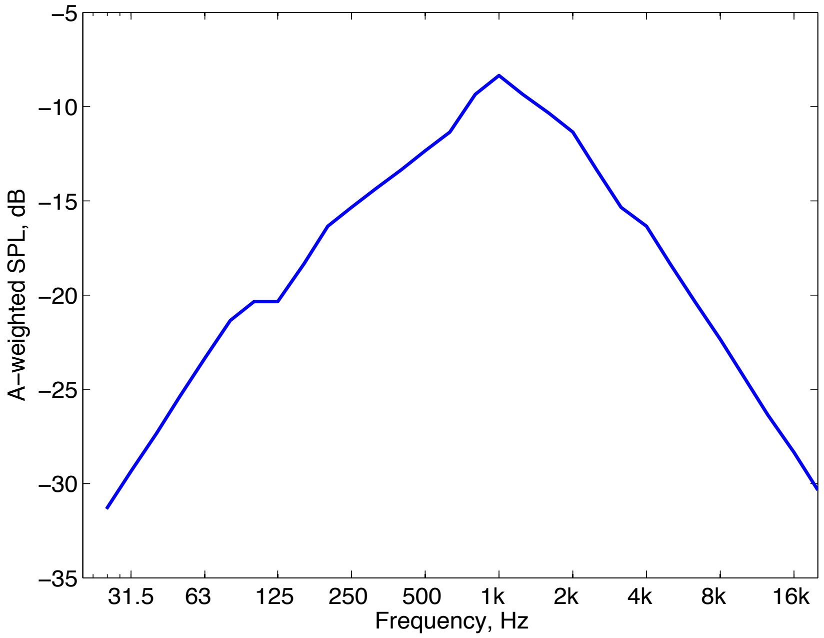

Figure 1. C_{tr} spectrum in the frequency extended version used here. Plotted is A-weighted sound pressure level, normalized to 0 dB(A).

The indoor noise level, $L_{p,indoor}$, is calculated using the conventional formula based on statistical room acoustical conditions and assuming a 0.5 s reverberation time, as follows

$$L_{p,indoor} = L_{p,outdoor} + 3 - R + 10\log(3S/V), \quad (1)$$

where $L_{p,outdoor}$ is the free field level outside the facade (i.e. omitting the facade reflection), R is the reduction index of the corresponding facade element with surface area S, and V is the room volume, see e.g. [2]. The reduction indices for the different facade elements, as shown in Figure 2 and tabulated in the Appendix, are used in the above formula (Eq. 1) with $L_{p,outdoor}$ given the values of the C_{tr} spectrum as shown in Figure 1 and Table 1. The resulting indoor spectra for each separate facade element is shown in Figure 3.

From making a combination of facade elements, i.e. selecting a type of wall, a window and an air intake, the total indoor level can be calculated by adding the separate contributions. Here, six different facade cases are selected that are suggested for further use within the project. The corresponding indoor noise levels are plotted in Figure 4 and listed in Table 1, where also data is given for a case with a partly open window.[1] The differences between outdoor and indoor single number levels are 30.6, 36.2, 34.7, 35.7, 38.3 and 41.4 dB(A) for cases 1–6, respectively. The first case, with the smallest difference between outdoor and indoor A-weighted level, uses the wooden facade, the old untreated window and the ordinary air intake. The other five cases all have the better air intake, which can be shown to give a negligible deterioration compared to having no air intake. The second case has the improved window (and the better air intake) and shows a significantly better overall sound insulation except at mid frequencies (around 800 Hz) and toward high frequencies. Cases 3 and 4 use both the new steel frame wall and, respectively, the two different new windows. It can be seen that this lightweight wall gives very poor performance at the lowest frequency bands and that the choice of window makes a significant difference above 100 Hz. Cases 5 and 6 use both the new concrete wall and, respectively, the two different new windows. Using the concrete wall is predicted to give a sound insulation at low frequencies that is better than the one from using the lightweight wall, but comparable to the one from using the wooden wall in case 2. Above 100 Hz, the use of the new noise proof window is predicted to result in a very high noise reduction.

The estimated apparent sound reduction index $R'_{tr,s,w}$, according to standard ISO 717-1, is listed for the selected cases 1–6, see Table 2. It can be noted that the results from the frequency extended C_{tr} spectrum used here largely agree with the standardized values of $R'_{tr,s,w} + C_{tr,50\text{-}5000}$ (or $R'_{tr,s,w} + C_{tr,50\text{-}3150}$), except for cases 3 and 4, where the standardized value under predicts the A-weighted indoor noise level by about 2 and 4 dB, respectively, due to the lightweight wall.

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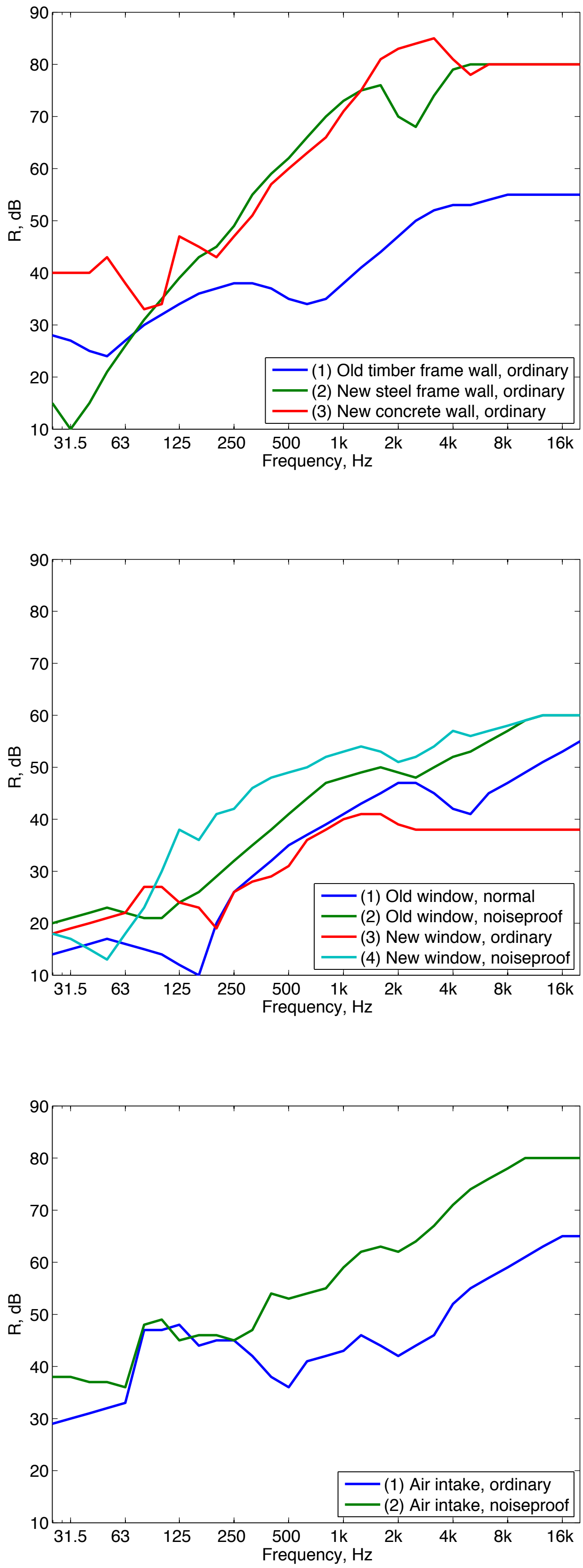
[1] Measured case in Report S13-01 by Patrik Andersson, Division of Applied Acoustics, Chalmers University of Technology, August 31, 2013. The Room has a floor area 12 m^2, ceiling height 2.5 m, window width 1.2 m, window height 1.4 m, and an opening slit width of 60 mm.

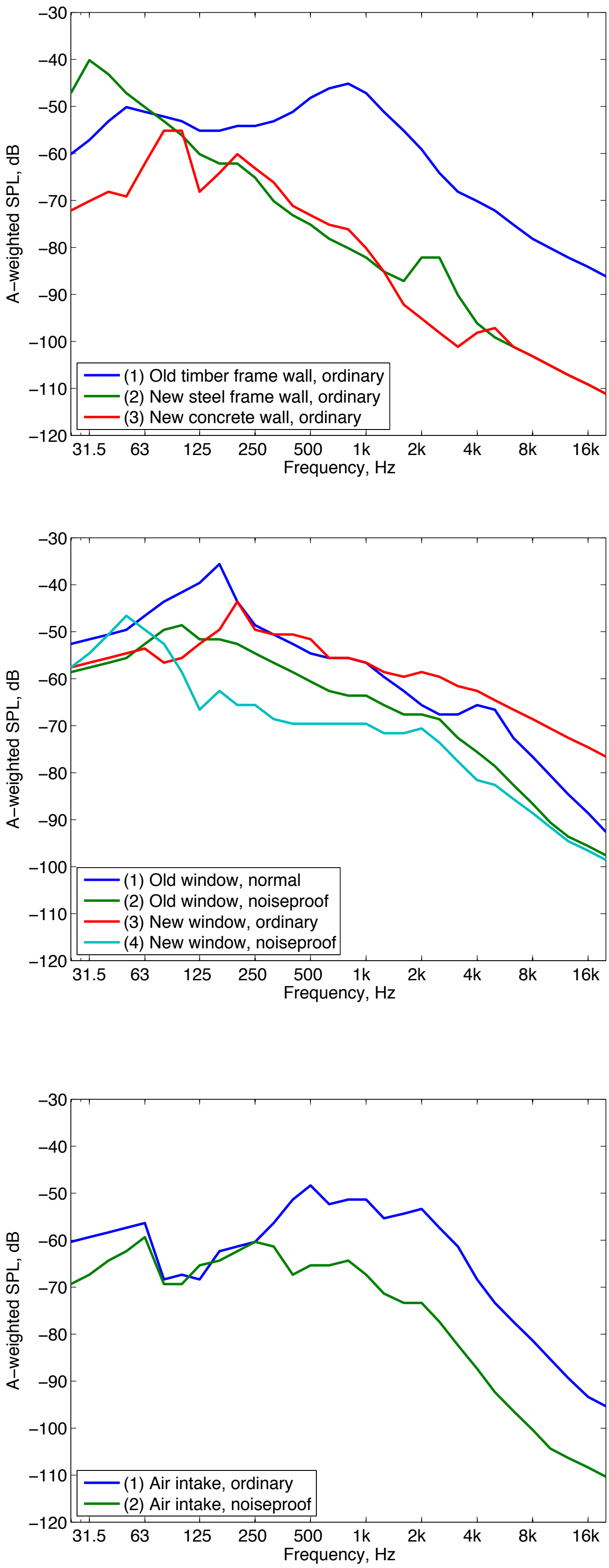


(a)

(b)

(c)

Figure 2. Reduction indices of the separate facade elements: (a) walls, (b) windows and (c) air intakes.



(a)

(b)

(c)

Figure 3. Calculated indoor noise levels for the separate facade elements: (a) walls, (b) windows and (c) air intakes.

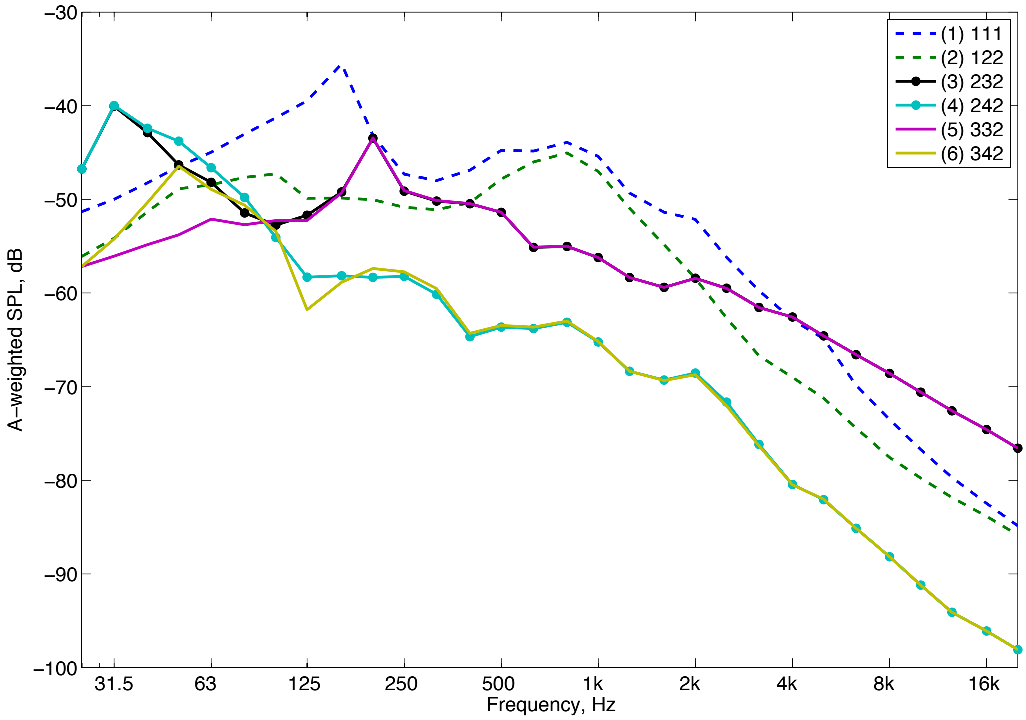


Figure 4. Calculated indoor noise levels for the suggested facade cases. The outdoor source strength is according to a frequency extended C_{tr} spectrum and the indoor level for each case is due to the combined transmission through wall, window and air intake. Key to the legend: first position is type of facade wall (1, 2 or 3), second position is type of window (1, 2, 3 or 4) and third position is type of air intake (1 or 2).

3. Conclusion

Reduction indices for selected facade elements, for the extended frequency range 25–20 000 Hz, have been used for making a set of six relevant cases, which are suggested for use within the project. The set of cases contain the use of three types of outer walls, four different windows and two different air intakes. Using an extended C_{tr} spectrum to characterize the source, the set gives a spread in outdoor to indoor level difference from about 31 to 41 dB(A). Also, standardized weighted apparent sound reduction indices are shown for the selected cases. In addition, data is given for a case with a partly open window.

4. Acknowledgement

The work presented here is part of the Swedish national project *Quieter Transport for More Efficient Distribution* and is financed by the VINNOVA program FFI Transport Efficiency. Project partners are Volvo Group; Chalmers University of Technology; SP Chemistry, Materials and Surfaces; and JABA Group.

5. References

[1] ISO 717-1:2013. Acoustics - Rating of sound insulation in buildings and of building elements - Part 1: Airborne sound insulation.

[2] Byggakustik - Ljudklassning av utrymmen i byggnader - Bostäder - Tillägg 1. Tillägg och rättelser till SS 25267:2004, utg. 3 - SS 25267:2004/T1:2009. SIS 2009.

Frequency [Hz]	$L_{p,outdoor}$	$L_{p,indoor}$ Case 1	$L_{p,indoor}$ Case 2	$L_{p,indoor}$ Case 3	$L_{p,indoor}$ Case 4	$L_{p,indoor}$ Case 5	$L_{p,indoor}$ Case 6	Sound reduction index for partly open window
25	-31.3	-51.3	-56.1	-46.8	-46.8	-57.2	-57.2	(5.2)
31.5	-29.3	-50.0	-54.2	-40.0	-40.0	-56.1	-54.2	(7.5)
40	-27.3	-48.2	-51.3	-42.9	-42.4	-54.8	-50.3	(5.1)
50	-25.3	-46.5	-48.9	-46.3	-43.8	-53.8	-46.4	(6.6)
63	-23.3	-45.0	-48.4	-48.2	-46.6	-52.1	-48.9	(8.3)
80	-21.3	-43.0	-47.7	-51.5	-49.8	-52.7	-50.6	(5.9)
100	-20.3	-41.3	-47.3	-52.8	-54.1	-52.3	-53.4	(7.4)
125	-20.3	-39.5	-49.9	-51.7	-58.3	-52.2	-61.8	9.3
160	-18.3	-35.5	-49.9	-49.2	-58.2	-49.3	-58.9	6.5
200	-16.3	-43.2	-50.0	-43.5	-58.3	-43.4	-57.4	12.7
250	-15.3	-47.3	-50.8	-49.1	-58.2	-49.1	-57.7	11.0
315	-14.3	-48.0	-51.1	-50.2	-60.1	-50.1	-59.5	10.7
400	-13.3	-46.9	-50.3	-50.5	-64.7	-50.5	-64.3	7.9
500	-12.3	-44.8	-47.8	-51.4	-63.6	-51.4	-63.5	7.3
630	-11.3	-44.8	-46.0	-55.1	-63.8	-55.1	-63.6	6.4
800	-9.3	-43.9	-45.0	-55.0	-63.1	-55.0	-63.0	8.8
1000	-8.3	-45.4	-47.0	-56.2	-65.2	-56.2	-65.2	8.1
1250	-9.3	-49.3	-51.0	-58.4	-68.4	-58.4	-68.4	8.5
1600	-10.3	-51.4	-54.9	-59.4	-69.3	-59.4	-69.3	7.8
2000	-11.3	-52.1	-58.4	-58.4	-68.5	-58.4	-68.7	7.8
2500	-13.3	-56.2	-62.7	-59.5	-71.7	-59.5	-72.1	8.6
3150	-15.3	-59.7	-66.7	-61.5	-76.2	-61.5	-76.3	7.1
4000	-16.3	-62.9	-69.0	-62.6	-80.4	-62.6	-80.5	8.4
5000	-18.3	-64.9	-71.2	-64.6	-82.1	-64.6	-82.0	11.5
6300	-20.3	-69.8	-74.4	-66.6	-85.1	-66.6	-85.1	13.8
8000	-22.3	-73.5	-77.6	-68.6	-88.2	-68.6	-88.2	13.7
10000	-24.3	-76.7	-79.8	-70.6	-91.2	-70.6	-91.2	11.3
12500	-26.3	-79.7	-81.8	-72.6	-94.1	-72.6	-94.1	5.5
16000	-28.3	-82.5	-83.8	-74.6	-96.1	-74.6	-96.1	(2.2)
20000	-30.3	-84.9	-85.8	-76.6	-98.1	-76.6	-98.1	
Total level [dB(A)]	0	-30.6	-36.2	-34.7	-35.7	-38.3	-41.4	

Table 1. Third-octave band values [dB] corresponding to the curves in Figure 4. Last row is the total A-weighted level for the extended frequency range. Right-most column is the apparent sound reduction index $R'_{tr,s}$ [dB] for the measured case with a partly open window. (The numbers in parenthesis are connected with a larger uncertainty.)

Reduction index [dB]	Case 1	Case 2	Case 3	Case 4	Case 5	Case 6
$R'_{tr,s,w}$	37	40	43	54	43	54
$R'_{tr,s,w} + C$	35	39	41	52	41	52
$R'_{tr,s,w} + C_{tr}$	31	37	38	48	38	48
$R'_{tr,s,w} + C_{100-5000}$	36	40	42	53	42	53
$R'_{tr,s,w} + C_{tr,100-5000}$	31	37	38	48	38	48
$R'_{tr,s,w} + C_{50-5000}$	36	40	42	51	42	52
$R'_{tr,s,w} + C_{tr,50-5000}$	30	36	37	40	38	42
$R'_{tr,s,w} + C_{50-3150}$	35	39	41	50	41	51
$R'_{tr,s,w} + C_{tr,50-3150}$	30	36	37	40	38	42

Table 2. Apparent sound reduction index $R'_{tr,s,w}$, according to standard ISO 717-1, for the selected cases 1–6.

Appendix:

Chalmers-Volvo: Ytterväggar, databas med ljudisolering 25-20000 Hz

Vårt ombud	Vår ref – uppdragsbeteckning	Ert ombud och postadress
Christian Simmons	1360	Chalmers tekniska högskola
Mölndal, vårt datum	Vårt dokument-ID	Jens Forssén
2013-05-30	SAURa-Chalmers-1360-Chalmers-Volvo_Ytterväggar-ljudisolering.docx	
Anm.		412 96 GÖTEBORG
Ert datum	Er beteckning	Er fax och e-postadress
	50060	Leverans: e-post/brev
		jens.forssen@chalmers.se

Distribution: Ombudet 1 ex.

Chalmers-Volvo: Ytterväggar, databas med ljudisolering 25-20000 Hz

Uppdrag

Beställaren uppdrog att ge exempel på reduktionstal för ett antal vanligt förekommande ytterväggskonstruktioner, fönster och luftintag inom ett utvidgat frekvensområde 25-20000 Hz. Se vidare i uppdragsbeskrivningen som skickades med e-post den 8 maj. Reduktionstalen är framtagna för att demonstrera hur olika ytterväggskonstruktioner kan påverka ljudnivåerna inomhus vid olika trafikslag samt för forskning och undervisning på Chalmers. De ska inte användas för projektering av byggnader med avseende på bullerskydd.

Metod

De reduktionstal som anges i tabell 1 baseras på mätdata eller teoretiskt beräknade data i frekvensområdet 50-5000 Hz och har hämtats från den nordiska databasen till BASTIAN (www.bastian.nu). En utvidgning har gjorts ned till 25 Hz och upp till 20 kHz, på basis av beräkningar och bedömningar enligt allmänt vedertagen teori för dubbelväggar (www.insul.co.nz). Reduktionstalen vid de lägsta frekvenserna har bedömts på erfarenhetsmässig grund med stöd av 1) värden vid högre frekvenser, 2) masslagen, 3) inverkan av grundresonans samt 4) ökad strålningsdämpning vid låga frekvenser. Vid höga frekvenser har reduktionstalen begränsats med tanke på 5) flanktransmission och 6) luftläckage. Huruvida denna blandning av teoretiska och empiriska metoder är giltig för det utvidgade frekvensområdet kan inte garanteras. Några få mätningar (ej publicerade) och en publicerad studie angående isolering mot ljud vid mycket låga frekvenser från vindkraftverk[1] indikerar att antagandet kan vara realistiskt, se figur 1. Att det är svårt att hitta mätdata beror på att ljudkraven inte går så långt ned (resp upp) i frekvens i något land och att mätstandarderna inte heller omfattar dessa frekvenser. Värdena i tabell 1 bör därför inte tolkas som någon garanti på vilken A-vägd ljudnivå som kan uppnås inne i en byggnad. Osäkerheten är sannolikt i den storleksordningen, att cirka vart tionde fall ligger 5 dB högre än beräknat.

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[1] Sound insulation of dwellings at low frequencies. Dan Hoffmeyer (1) and Jørgen Jakobsen (2). Artikeln baseras på rapport AV 1097/08 från DELTA Akustik & Vibration. 1) DELTA, Venlighedsvej 4, DK-2970 Hørsholm. 2) Dansh Environmental Protection Agency, Strandgade 29, DK-1401 København K. J of Low Frequency Noise, Vibration and active control Vol. 29 2010.

DELTA
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AV 1097/08
Page 17 of 27

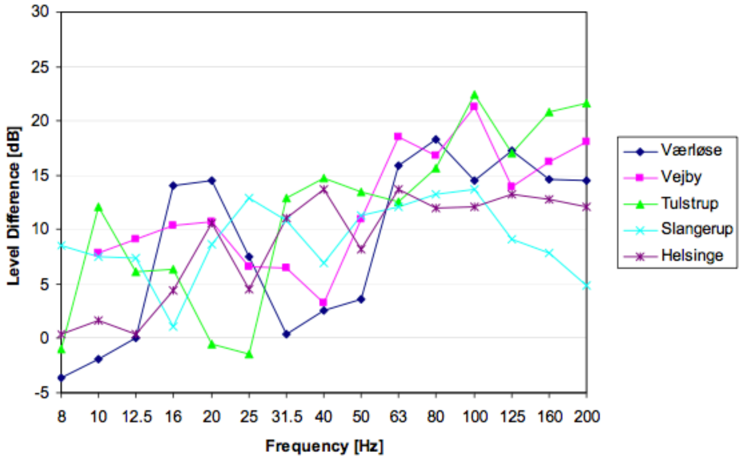


Figure 7
Measurement results for five living rooms. Outdoor/indoor level differences in dB per one-third octave measured with the specified method.

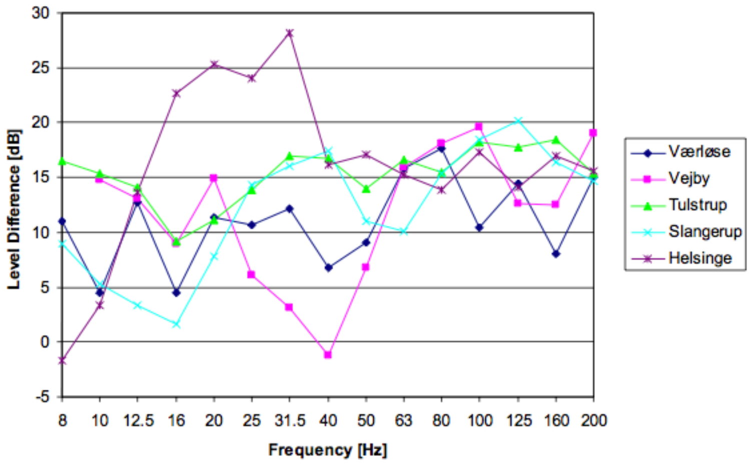
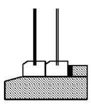
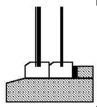
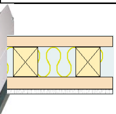
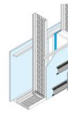


Figure 8
Measurement results for five small-sized rooms. Outdoor/indoor level differences in dB per one-third octave measured with the specified method.

Figur 1. Ljudnivåskillnad ute-inne, mätt vid fasad och i rumshörn. Under 50 Hz varierar ljudnivåskillnaden mer än vid högre frekvenser. Placering av mikrofonen i hörnen minskar inverkan av stående våg i rummet men ger upp till 3 dB högre ljudnivå än rumsmedelvärdet enligt ISO 140-5. Från DELTA Akustik & Vibration, se fotnot (1).

Resultat

Tabell 1a. Fönster, uteluftintag och ytterväggar, beskrivning till tabell 1b.

Area, m²	1,88	1,88	1,5	1,5	10	10	10	10	10
Name	Old window, normal	Old window, noi-seproof	New window, ordinary	New window, noi-seproof	Air in-take, ordinary	Air intake, noiseproof	Old timber frame wall, ordinary	New steel frame wall, ordinary	New concrete wall, ordinary
Description	3 mm glass, coupled sashes spaced 40 mm, 3 mm glass (opens outward, working sealant)	4/2/4mm laminate glasses, coupled sashes spaced 39 mm, 4 mm glass (opens outward, working sealant)	4 mm glass, 16 sealed distance, 6 mm glass (single sash with a sealed IGU, Argon)	6 glass, 180 air, 4/0,76/4 laminate glasses, 16 dist., 4 glass, (sepa-rate sashes, common frame)	Silencer 800x100 x30 mounted in niche, air intake through frame, slot 360x 120 mm	Silencer "Z-channel" built-in-wall, air intake under window	50 wood plank, 50 wood dust, 50 wood plank, 30 plaster inside	Plaster 5 on ment-boards 12, Studs 25, wheather-board 9,5 on steel studs and mineral wool 195, channels 45, interior plaster-boards 25	Sand-wich Type1: 75 concrete, 150 concrete, 150 mineral wool
BASTIAN - ID	SAU F1-0	SAU F1-b4	Elit 04 EDI-ETI-AL	DOM-LUX 09 230	Fresh_0 6 AL-dB-800	Fresh_04 ZK-dB RF100-T	SAU 16 V5-0	Knauf Danogips_ 04	SvBtg_0 1 Sand-wich facade
Res freq. f0 or fL (Hz)	158	117	193	52	500	70	57	35	14
Coinc freq. fc (Hz)	4190	3142	3142	2095	N/A	N/A	400	3142	242
Mass (least single-sided)	7,2	10	10	15	N/A	N/A	25	18	180
Picture									
Rw [dB]	35	43	35	51	42	57	40	60	60
C [dB]	-5	-2	-1	-1	0	-1	-1	-2	-2
Ctr [dB]	-10	-7	-4	-5	0	-4	-2	-8	-9
RA,tr (=Rw+Ctr)	25	36	31	46	42	53	38	52	51

Tabell 1b. Reduktionstal för fönster, uteluftintag och ytterväggar. Blåa värden är empiriskt uppskattade enligt metodavsnittet, motsvarande mätning i laboratorium, utan marginaler

Name Freq (Hz)	Old window, normal	Old window, noiseproof	New window, ordinary	New window, noiseproof	Air intake, ordinary	Air intake, noiseproof	Old timber frame wall, ordinary	New steel frame wall, ordinary	New concrete wall, ordinary
25	**14**	**20**	**18**	**18**	**29**	**38**	**28**	**15**	**40**
31,5	**15**	**21**	**19**	**17**	**30**	**38**	**27**	**10**	**40**
40	**16**	**22**	**20**	**15**	**31**	**37**	**25**	**15**	**40**
50	17	23	21	13	32	37	24	21	43
63	16	22	22	18	33	36	27	26	38
80	15	21	27	23	47	48	30	31	33
100	14	21	27	30	47	49	32	35	34
125	12	24	24	38	48	45	34	39	47
160	10	26	23	36	44	46	36	43	45
200	20	29	19	41	45	46	37	45	43
250	26	32	26	42	45	45	38	49	47
315	29	35	28	46	42	47	38	55	51
400	32	38	29	48	38	54	37	59	57
500	35	41	31	49	36	53	35	62	60
630	37	44	36	50	41	54	34	66	63
800	39	47	38	52	42	55	35	70	66
1000	41	48	40	53	43	59	38	73	71
1250	43	49	41	54	46	62	41	75	75
1600	45	50	41	53	44	63	44	76	81
2000	47	49	39	51	42	62	47	70	83
2500	47	48	38	52	44	64	50	68	84
3150	45	50	38	54	46	67	52	74	85
4000	42	52	38	57	52	71	53	79	81
5000	41	53	38	56	55	74	53	80	78
6300	**45**	**55**	**38**	**57**	**57**	**76**	**54**	**80**	**80**
8000	**47**	**57**	**38**	**58**	**59**	**78**	**55**	**80**	**80**
10000	**49**	**59**	**38**	**59**	**61**	**80**	**55**	**80**	**80**
12500	**51**	**60**	**38**	**60**	**63**	**80**	**55**	**80**	**80**
16000	**53**	**60**	**38**	**60**	**65**	**80**	**55**	**80**	**80**
20000	**55**	**60**	**38**	**60**	**65**	**80**	**55**	**80**	**80**

Underlag

En generell specifikation av byggdelar lämnades av uppdragsgivaren, som vi har preciserat utifrån tillgängliga uppgifter i databasen.

Vi tackar för uppdraget.

Med vänlig hälsning
Simmons akustik & utveckling ab

Christian Simmons
Bilaga: Resultaten har även skickats som Excel-fil.