Calculation of noise in residential environments

Zbigniew Koziel*, Eulalia Peris, James Woodcock, Gennaro Sica,
Andrew T. Moorhouse, David C. Waddington

Acoustics Research Centre, Newton Building, University of Salford, Salford, M5 4WT, UK

* corresponding author: Z.Koziel@edu.salford.ac.uk

ABSTRACT

The DEFRA funded project "*Human Response to Vibration in Residential Environments*" investigates relationships between human response in residential areas, primarily in terms of annoyance, and combined effects from exposure to vibration and noise. This paper focuses on the results from the analysis of noise exposure in this study, in particular from construction work and railway traffic. The exposures for railway traffic noise sources were obtained and calculated according to a routine based on Calculation of Railway Noise(1) (Department of Transport 1995) and "Additional railway noise source terms for 'Calculation of Railway Noise (2007)'" (Department of Transport 2007). On the other hand, exposure from construction work was calculated based on measurements of the various sources at different locations. This paper compares noise exposures from those sources in terms of level of noise, frequency content, distance from source to receiver, and the environment in which residents are exposed to noise and the reported annoyance. To conclude, the paper shows the relationships between noise exposure from the different vibration sources and annoyance. [Work funded by the Department for Environment, Food and Rural Affairs (Defra) UK].

INTRODUCTION

Environmental noise is the effect of single or combined sources generating sound. Noise exposure, affecting residential environments, has its source in railway, construction, aircraft traffic, and road traffic. Additional to the effects from different noise sources, residential environments are also exposed, to a greater or lesser extent, to vibration. This combination of exposures has already been investigated in Sweden in a similar project called TVANE (Öhrström et al. 2008). TVANE also analyzed similar problems regarding combination of noise and vibration. This project "*Human Response to Vibration in Residential Environments*", funded by Defra, also investigated combined effects of exposure to noise and vibration.

This paper outlines the process of calculation of noise exposure from different sources, such as railway traffic and construction work. Although some analysis regarding the exposure - response relationship has been included, the detailed information of this topic, regarding combined effects, can be found in Technical Report 6 "*Determination of Exposure-Response Relationships*" (Woodcock et al. 2011.)

BACKGROUND

For the purposes of the project "*Human Response to vibration in residential environments*", all sites were carefully chosen to fulfill the main objectives, which were to measure vibration in the vicinity of railway and construction sources. A great number of vibration measurements were conducted around the Midlands and North-west of

[1] Calculation of Railway Noise (Department of Transport 1995) is denoted as CRN throughout this paper

England. On the other hand, measurement of construction sources took place in South and Site B. Measurements of construction activities covered a process of building new light railway in Manchester.

Variations were found in terms of the noise levels attributable to the different sources (construction and railway), although these variations were also observed in different locations of the same sources themselves.

This paper presents the outline of the results from the noise measurements. For the details regarding the measurement of vibration, calculation of noise, and determination of exposure-response relationship, it is suggested the technical reports published by Defra are read (Sica et al. 2011; Woodcock et al. 2011).

METHODOLOGY

Noise metrics

To express an overall noise exposure over a 24 h time period, a noise descriptor such as L_{den} has been chosen. It is defined in terms of average sound pressure level during daytime (07:00 - 19:00), evening (19:00 - 23:00) and night time (23:00 - 07:00) and imposes a 5 dB penalty during the evening and 10 dB penalty during the night time. L_{den} is calculated from the following formula

$$L_{den} = 10\log_{10}\left(\frac{12\times10^{L_{day}/10} + 4\times10^{(L_{evening}+5)/10} + 8\times10^{(L_{night}+10)/10}}{24}\right) \quad (1)$$

L_{den} has been defined in the EC (Directive 2002/49/EC 2002) and adapted during investigation of exposure - response relationships in similar research (Miedema & Oudshoorn 2001; Miedema 2004; Miedema & Vos 1998).

In terms of railway traffic, noise exposure L_{den} was obtained from CRN (Department of Transport 1995). On the other hand, noise exposure from construction activities was obtained from measurement of all possible sources during the daytime only. As such, an average $L_{Aeq,10h}$, has been used as a proxy for L_{day}, the exposure being assumed negligible in the remaining two hours of the day. The Code of Practice BS 5228-1:2009 (BSI 2009) was found to be helpful to develop a proper routine for determination of noise exposure from construction work. Additionally, an intermediate noise descriptor L_{AE}[(2)] was also applied due to its flexibility for calculation of overall noise level from a number of similar sources.

Calculation of noise from railway sources

Although a few noise measurements have been conducted according to BS 7445-2:1991 (BSI 1991), noise exposure from railway traffic was obtained from calculation based on Calculation of Railway Noise (CRN).[(1)] This well-known Code of Practice provides a routine for determining noise exposure, covering a vast number of conditions. For predictive purposes, information about a number of passenger and freight trains were obtained from accelerometers, which monitored vibration for 24 hours

[2] Sound Exposure Level (abbreviated as L_{AE} or SEL) applies to discrete noise events and is defined as the constant level that, if maintained during a 1 s interval, would deliver the same A-weighted sound energy to the receiver as the real-time varying event. It can be also understood as a $L_{Aeq,T}$ normalized for T = 1 s (Crocker 2007)

(see Figure 1). An algorithm, detecting the number of trains from vibration, has been applied in order to provide an estimation of railway traffic. The majority of measurements of vibration involved more than one accelerometer per site. Therefore an average number of train occurrences from all control positions was calculated. A detailed explanation has been included in Technical Report 3 (Sica et al. 2011).

CRN defines a routine covering all details influencing the final noise emission from vehicles passing by a point of reception. Additionally, CRN covers site topography, ground reflection, number of vehicles per train, number of trains per 24 h, air absorption (although this is primarily a high frequency effect), a distance correction, barrier attenuation, reflections from facades, and reflective contributions of buildings surrounding the point of reception. The most significant and accurate approach demands a great deal of specific and detailed information about sites which were not available.

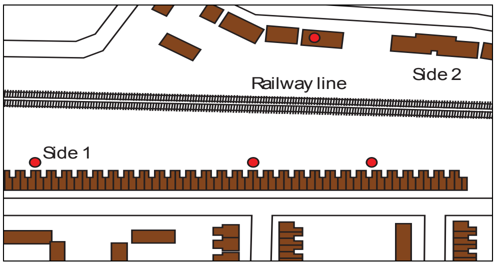

Figure 1: Plan view of one of the sites where vibration measurements took place. Two sites are covered by the same rail line. Residents were exposed to vibration from the same rail line. Vibration was monitored for 24 h by all control positions, indicated by red spots.

Table 1 presents an example of the number of passenger and freight trains detected by the algorithm mentioned above.

Table 1: Example of estimating the number of passenger and freight trains on a site

	Day	Evening	Night
No of passenger trains	117	40	23
No of freight trains	1	1	2

Calculation of exposure to construction noise

The main difference for construction work relates to the character of the noise and its frequency content. On one hand, piling, as one of the main activities, has been found to be an impulsive and repetitive noise source. On the other hand, more uniformly distributed noise sources were found in Site B, including saw-cutting, flattening etc. Background noise level was significantly high to increase uncertainties during the measurements.

The concept of determination of exposure was similar to that for railway noise and the routine was based on the Code of Practice BS 5228-1:2009. Unlike CRN, noise exposure has been established according to L_{AE} obtained from field work, where construction plants have been measured individually. According to BS 5228-1:2009, noise descriptors were normalized to a 10 m distance between the source and reception point. An equivalent-continuous sound pressure level $L_{Aeq,T}$ was adjusted to a

10 h period, which is similar to L_{day}, a daytime average $L_{Aeq,T}$, yet does not always represent the same value[3]. Finally, all sources were logarithmically summed.

Different approaches to measurements were adopted in East and Site A due to limitations, mostly due to space. A more direct path was found in Site A though. In Site B, a SLM[(4)] was positioned in a free field (Figure 2, right pane) due to difficulties in obtaining access to private areas with façades.

In Site A (left pane of Figure 2), the SLM was installed about 15 m away from the sources, at a distance of 1 m from the most exposed façade and 1.5 m above ground level.

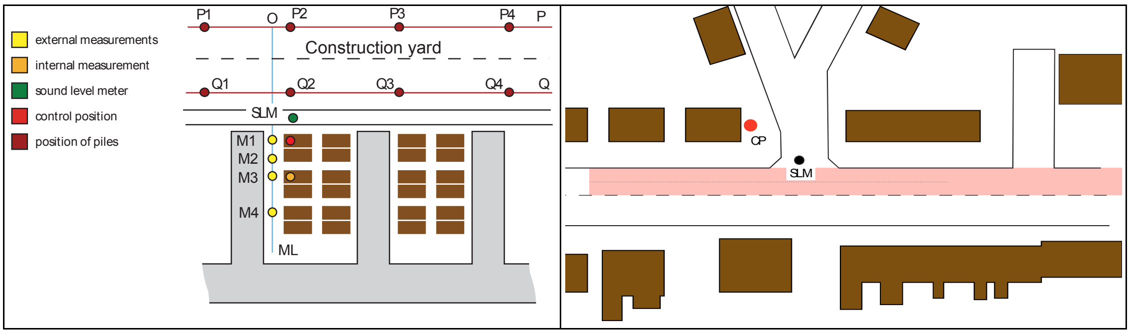

Figure 2: Plan view of two sites where vibration and noise measurements took place. Left pane: site in Site A, right pane: site in Site B

RESULTS

Railway noise exposure

This section presents an outline of the results from the calculation of the 24 h exposure to noise from railway traffic. For the purpose of this project, the exposure was quantified with L_{den}, which required a minor modification of the calculation routine given in CRN.

At the time of the measurements, there was a great variation in freight train occurrences. Additionally, freight trains were difficult to anticipate as they are not regularly scheduled, unlike passenger trains. There was also a limited number of dedicated rail lines along which freight trains are allowed to travel. Table 2 presents the results of the prediction obtained from the calculation based on the CRN.

The left hand-side graph in Figure 3 shows a comparison of the noise spectrum of a typical passenger train and a construction source both normalized to a 10m distance. It can be observed that higher frequency bands of the railway source contain much lower levels than the construction source.

The level of annoyance versus number of respondents is presented in right-hand side graph of the Figure 3. Comparing this graph with right-hand side graph of the Figure 5, it can be observed that higher percentage of respondents reported higher annoyance due to construction noise.

[3] For details, refer to the European Directive (Directive 2002/49/EC 2002)
[4] SLM is denoted as Sound Level Meter throughout this document

Table 2: Number of Control Positions installed at different railway sites

	Site A	Site B	Site C	Site E	Site F	Site H	Site I	Site J	Site K	Site L
No of respondents	115	30	9	64	61	87	155	235	45	43
Av. L_{den}	57.9	58	53.8	67.2	59.6	62.2	63.2	60.2	61	62.9
Min L_{den}	40.4	49.7	51.3	58.6	54.4	56.9	57	53.1	49.6	57.4
Max. L_{den}	61.2	61.5	56	73.9	63.1	68	68.6	66.9	70.4	67.4

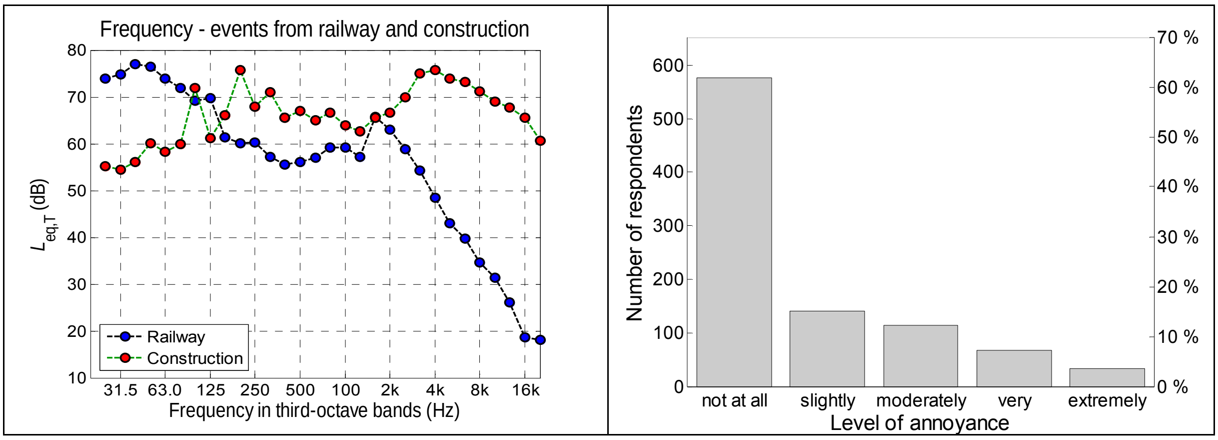

Figure 3: This figure presents, on left-hand side graph, the comparison between noise spectrum from railway and construction. The right-hand side graph presents number of respondents exposed to railway noise versus level of annoyance in 5-point semantic scale (DD ISO/TS 15666:2003).

The estimated cumulative probabilities of annoyed respondents as functions of L_{den} are included in Figure 4. The left-hand side graph shows residents reported to be "annoyed" and "highly annoyed" (the categories 4 and 5 in 5-point semantic scale, DD ISO/TS 15666:2003). The right-hand side graph shows residents reported to be "highly annoyed".

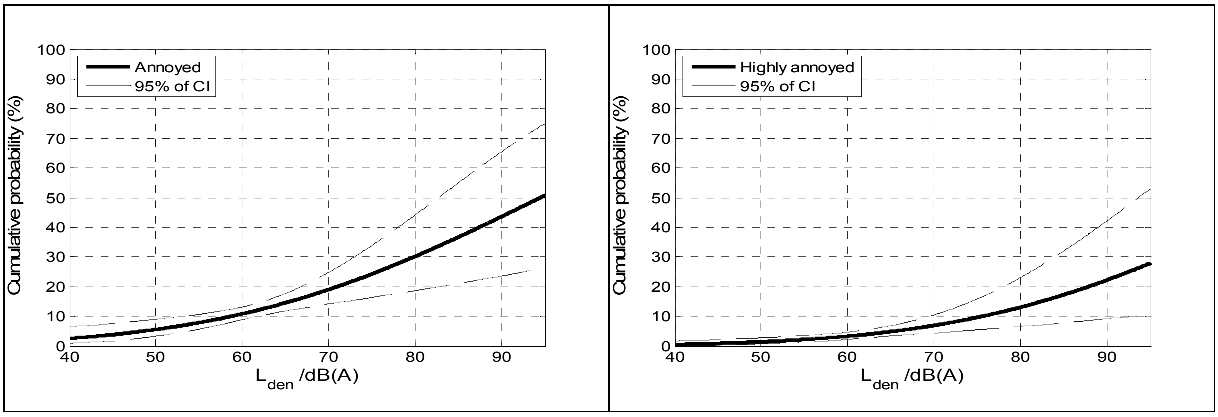

Figure 4: The exposure-response relationship between railway noise and annoyance measured in 5-point semantic scale (DD ISO/TS 15666:2003)

The results from estimation of the ordinal probit regression model, is shown in Table 3. The overall model and its coefficients were found to be significant.

Table 3: Results from ordinal probit model analysis due to noise from railway and annoyance level

Variables		Estimated thresholds	Std. Error	95% CI	Signific.
Dependent var. (annoyance level)	"4" + "5" (5)	3.3878	0.6091	2.1939 – 4.5818	0.00*
	"5" (5)	3.9926	0.6137	2.7898 – 5.1954	0.00*
Ind. variable (L_{den})	L_{den}	-0.0359	0.0098	-0.0552 – -0.0166	0.00**

* p<0.0001, ** p<0.0005; for total model: χ-test p<0.0001; N = 816.

Construction noise exposure

This section provides the outline results from calculation of noise and the prediction of annoyance from construction work. The typical frequency content of a construction source is shown by left-hand side graph of the Figure 3. The overall noise level affecting the community is shown in Figure 5. Three different groups of bars correspond to three groups of community, as followed: (a) combined group of people from two sites, (b) separate community groups exposed to noise in Site B and (c) Site A.

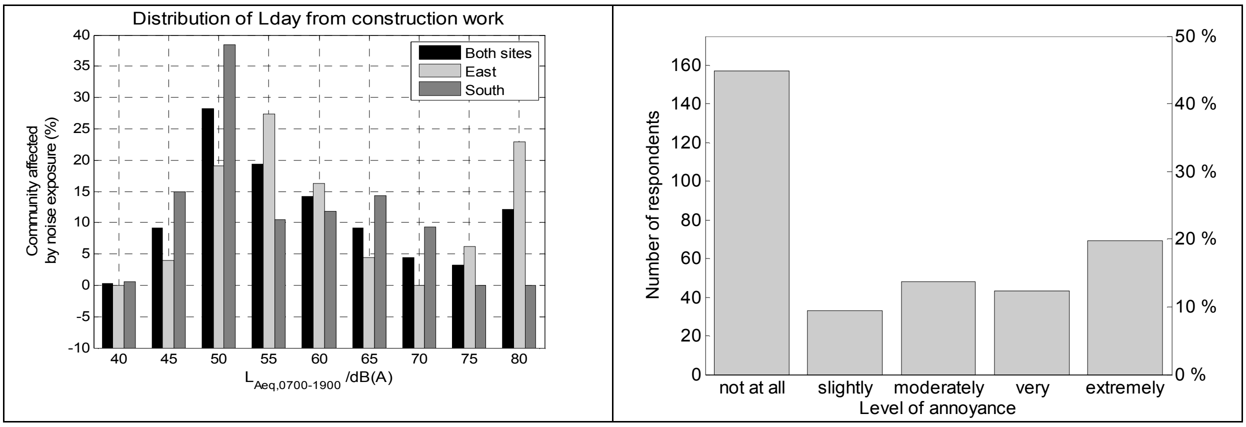

Figure 5: This figure presents 2 graphs, the percentage of residents exposed to noise levels from construction sites (an overall exposure, exposure from South and East) and number of respondents versus annoyance level in 5-point semantic scale (DD ISO/TS 15666:2003).

The largest number of respondents are subjected to 50 dBA considering combined sites. In Site A, the majority of respondents were affected by noise levels around 50 dBA. In Site B, on the other hand, two distinct groups are subjected to a noise level L_{den} equal to 55 dBA and 80 dBA. The highest values of noise level was the result of a point of reception being in close vicinity to a source whereas the lowest value of the noise level was caused by a reduction due to obstacles and shielding.

Similarly to Figure 4, Figure 6 shows two graphs that contain the estimated cumulative probabilities of annoyed respondents as functions of L_{day}. The left-hand side graph shows residents reported to be "annoyed" and "highly annoyed" (the categories 4 and 5 in 5-point semantic scale, DD ISO/TS 15666:2003). The right-hand side graph shows residents reported to be "highly annoyed".

[5] In 5-point semantic scale (DD ISO/TS 15666:2003), the categories are named as followed: "0 - do not notice", "1 - not at all", "2 - slightly", "3 - moderately", "4 - very", "5 - extremely"

The results from estimation of the ordinal probit regression model are shown in Table 4. The overall model and its coefficients are highly significant.

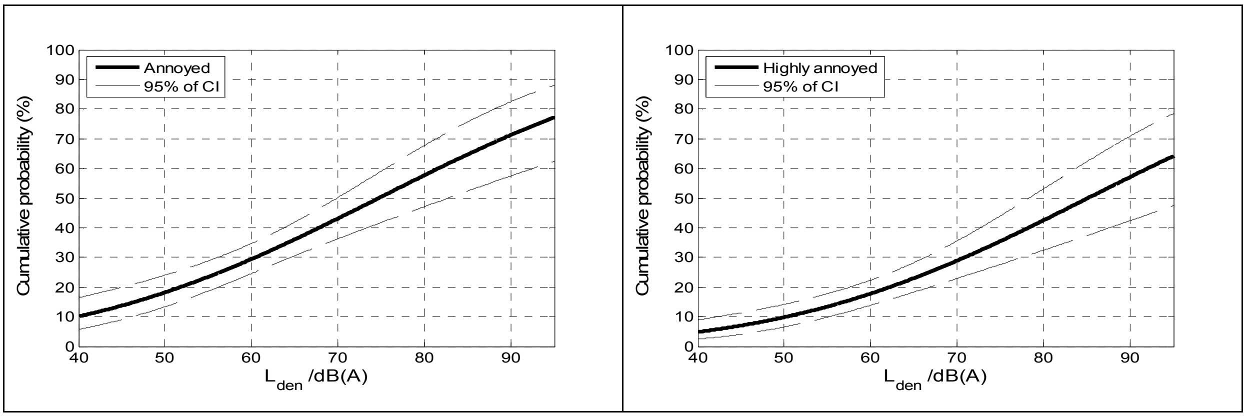

Figure 6: The exposure-response relationship between construction noise and annoyance measured in 5-point semantic scale (DD ISO/TS 15666:2003)

Table 4: Results from ordinal probit model analysis due to noise from construction and annoyance

Variables		β_0 and β_1	Estimated thresholds	Std. Error	95% CI		Significance
Dependent var. (annoyance level),	β_0	"4" + "5" (5)	2.7455	0.3869	1.9872	3.5039	0.00*
		"5" (5)	3.1282	0.3928	2.3583	3.8982	0.00*
Ind. variable (L_{den})	β_1		-0.0367	0.0098	-0.0552 –	-0.0166	0.00*

* $p<0.0001$; for total model: χ-test $p<0.0001$; N = 324.

UNCERTAINTIES ASSOCIATED WITH CALCULATION

Uncertainties were estimated based on the paper of Craven & Kerry (2001) and were followed by calculation also included in Technical Report 3 by Sica et al. (2011).

Uncertainties, related to railway noise, had to be estimated due to assumptions, which covered the number problems. Most of them are related to the number of vehicles that a train is comprised of, the number of trains during the daytime, evening and night time, the distance between the source and receiver that were estimated from maps, and speed of trains travelling through residential areas. The combined uncertainties were found to be 2 dBA, including 95% confidence interval.

Uncertainties in construction sites were caused by sources of much greater noise level and limited dynamic range of spectral content measurements. Due to different positions of sources, a ground reflection component did not always influence the final results. Additionally, larger uncertainties were set due to the limited dynamic range of the SLM when measuring the spectral content of loud sources (exceeding 80 dBA). Expanded uncertainty (95% confidence [k = 2]) was found to be 4.5 dBA.

CONCLUSION

The main purpose of the survey presented here was to obtain exposure-response curves for vibration from railway and construction sources. However, participants were also asked about annoyance due to noise and the resulting data was sufficiently detailed to permit the derivation of exposure-response relationships for noise from the same sources which are presented here. These curves thus serve to complement the exposure response curves derived for vibration.

The curves indicate that, for the same exposure, expressed in terms of L_{den}, the annoyance due to construction noise is greater than that from railways. We can speculate that factors other than noise and vibration, such as dust and disruption to traffic etc. contribute to the higher annoyance from construction.

Details of the vibration survey which was carried out at the same time as the noise survey can be found in Technical Report 3 "*Calculation of vibration exposure*" (Sica et al. 2011).

REFERENCES

BSI (1991). Description and measurement of environmental noise — Part 2: Guide to the acquisition of data pertinent to land use (BS 7445-2:1991). London: British Standard Institution. Retrieved from http://bsol.bsigroup.com

BSI (2009). Code of practice for noise and vibration control on construction and open sites – Part 1*:* Noise (BS 5228-1:2009). London: British Standard Institution. Retrieved from http://bsol.bsigroup.com

Craven NJ, Kerry G (2001). A good practice guide on the sources and magnitude of uncertainty arising in the practical measurement of environmental noise. Salford: School of Acoustics & Electronic Engineering, University of Salford.

Crocker MJ (2007). Noise and vibration control. New Jersey: John Wiley & Sons, Inc.

Department of Transport. (1995). Calculation of railway noise.

Department of Transport. (2007). Additional railway noise source terms for "Calculation of Railway Noise 1995". A report produced for Defra by AEAT.

Directive 2002/49/EC (2002). Directive 2002/49/EC of the European Parliament and the Council of 25 June 2002 relating to the assessment and management of environmental noise. Off J Europ Commun 189(12): 12-25.

ISO/TS 15666(2003). Acoustics. Assessment of noise annoyance by means of social and socio-acoustics surveys (DD ISO/TS 15666:2003). London: British Standard Institution. Retrieved from http://bsol.bsigroup.com

Miedema HME (2004). Relationship between exposure to multiple noise sources and noise annoyance. J Acoust Soc Am 116: 949.

Miedema HM, Oudshoorn CG (2001). Annoyance from transportation noise: relationships with exposure metrics DNL and DENL and their confidence intervals. Environ Health Perspect 109: 409.

Miedema HME, Vos H (1998). Exposure-response relationships for transportation noise. J Acoust Soc Am 104: 3432.

Öhrström E, Ögren M, Jerson T et al. (2008). Experimental studies on sleep disturbances due to railway and road traffic noise. In: Griefahn B (ed): 9th International Congress on Noise as a Public Health Problem (ICBEN) 2008, Foxwoods, CT.

Sica G, Peris E, Woodcock J et al. (2011). Human response to vibration in residential environments (NANR209), Technical Report 3: Calculation of vibration exposure. Defra (London).

Woodcock J, Peris E, Sica G et al. (2011). Human response to vibration in residential environments (NANR209), Technical Report 6: Determination of exposure-response relationships. Defra (London).