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Instructions for processing of near field reflectivity test data and derivation of far field reflectivity indicators

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1 Introduction

Sound reflectivity is one of the intrinsic acoustical characteristics of noise reducing devices (NRD's). It describes which percentage of an incident sound field is reflected back towards the opposite side of the road. The reflectivity is determined by the absorption properties of the material of the NRD as well as by the geometrical shape of the NRD, which may enhance or reduce sound reflections in particular directions. The reflectivity effect in the far field is thus not only related to the NRD and its design, but also to the receiving position in the far field.

The main task of QUIESST Work Package 2 was to develop an engineering method for the extrapolation of the results of the near field reflectivity test developed in WP 3 to estimate the contribution of reflected sound to the sound levels in the far field of a NRD.
In the Final report of WP 2 all development steps to achieve the intended engineering method are described in detail.

The final result of WP 2 is an engineering computation method that gives the values of two far field reflectivity performance indicators (for High-rise and Low-rise buildings) for a particular NRD type.

In this deliverable the characteristics of the engineering extrapolation method are described and instructions for use of the method are given.

The format of this description is that of an Annex to a European Standard. This format is used with the intention that the engineering extrapolation method shall be used in conjunction with the revised near field reflectivity test method developed in WP 3. This test method is intended to replace the method in the current European Standard EN 1793-5:2002 and the engineering extrapolation method may then be added to the revised standard as an Annex.

For an easy use of the engineering extrapolation method it is implemented in a pre-programmed Excel spread sheet. The spread sheet will be published together with this present report and can be downloaded from the QUIESST website (www.quiesst.eu).
It may also be distributed together with the revised version of EN 1793-5.

2 Text of future Annex C to EN 1793-5

Annex C
(Informative)

Extrapolation of near field reflectivity test results to estimate the contribution of reflected sound in the far field

C.1 General

One of the deliverables of Work Package 2 of the QUIESST project is an engineering computation method that gives the values of two far field performance indicators (for High-rise and Low-rise buildings) for a particular NRD type.
The method uses as input the results of the near field reflection test treated in this standard. The third-octave band values of the averaged Reflection Index (RI) values are the basis for the computations. Also the NRD type and the geometrical shape parameters have to be entered to execute the extrapolation analysis.
The output of the analysis is an estimate of the contribution of the reflected sound to the sound level in the far field, expressed as the single number rating for the far field reflection index: $DL_{\mathrm{RI,ff}}$.
This single number rating in dB(A) is computed for five different receiver positions. These positions are all located at a distance of 100 m from the reflecting NRD and at heights of 1,5, 5, 10, 20 and 40 m above the ground. The far field reflection index RI_{ff} is defined as the ratio between the amount of energy that is reflected by the NRD in question and the energy that would be reflected by a reference NRD. As a reference a flat rigid vertical NRD of the same height as the test sample is chosen (in this extrapolation method the height is assumed to be 4 m).

In order to obtain a compact description of the reflection effects in the far field the single number ratings at the five positions are clustered and averaged in two groups: the average of the single number ratings of the three lowest positions $DL_{\mathrm{RI,ff.LR}}$ is considered to be representative for receiving positions in front of Low-rise buildings and the average of the single number ratings of the highest two positions $DL_{\mathrm{RI,ff,HR}}$ is considered representative for receiving positions in front of High-rise buildings.
This way two far field indicators are presented to characterise the far field reflectivity of NRD test samples; see Equations (C.1) and (C.2)

$$DL_{RI,ff,LR} = \frac{DL_{RI,ff,1.5m} + DL_{R,Iff,5m} + DL_{RI,ff,10m}}{3} \tag{C.1}$$

$$DL_{RI,ff,HR} = \frac{DL_{RI,ff,20m} + DL_{RI,ff,40m}}{2} \tag{C.2}$$

In which:

$DL_{RI,ff,xm}$ is the Single Number rating of sound reflection in the far field determined for a receiving position at 100 m distance from the reflecting NRD and at a height of *x* m above the ground, according to equation (C.3)

$$DL_{RI,ff} = -10\log\left(\frac{\sum_f RI_{ff} \cdot 10^{0.1L_i}}{\sum_f 10^{0.1L_i}}\right) \quad \text{(C.3)}$$

$DL_{RI,ff.LR}$ is the average Single Number rating for the three lower receiving positions, representative for low rise buildings

$DL_{RI,ff,HR}$ is the average Single Number rating for the two higher receiving positions, representative for high rise buildings

RI_{ff} is the ratio between the amount of energy that is reflected by the NRD under test and the energy reflected by a reference NRD per 1/3-octave band, according to equation (C.4):

$$RI_{ff} = \frac{\left(\left|P_{data}(f)\right| - \left|P_{free}(f)\right|\right)^2}{\left(\left|P_{ref}(f)\right| - \left|P_{free}(f)\right|\right)^2} \quad \text{(C.4)}$$

In equation (C.4) is:

P_{data} the complex pressure at a far field receiving position computed for the NRD under test

P_{ref} the complex pressure at a far field receiving position computed for the reference NRD

P_{free} the complex pressure in a free field originating from the same source position, but without reflection contributions.

In both situations the free field complex pressure P_{free} is subtracted in order to obtain only the contribution of the reflected sound.

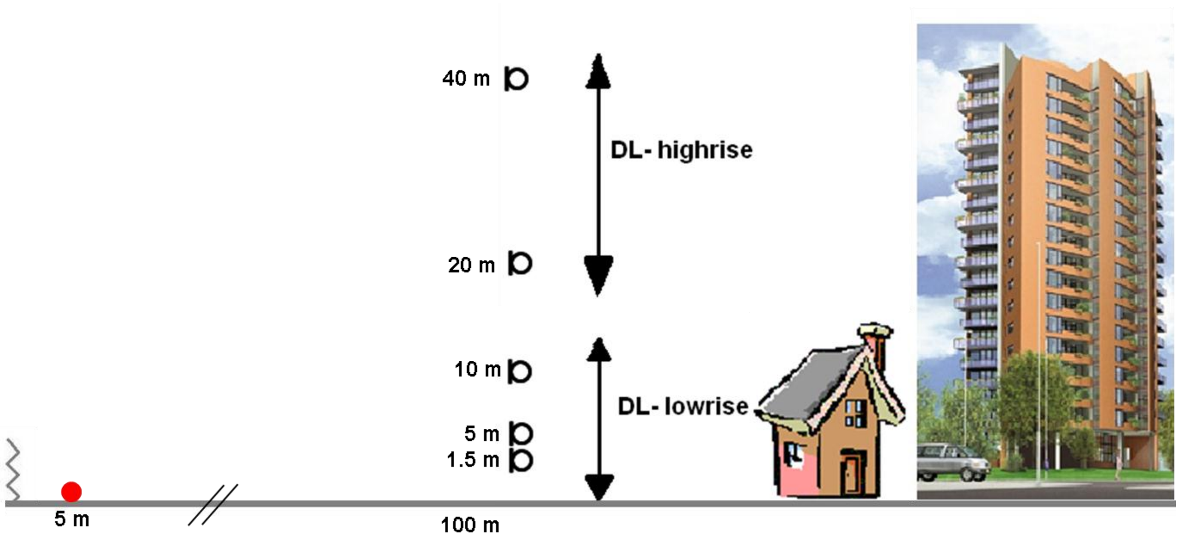


Figure C.1 - High rise and low rise buildings, with receiving positions at 1.5, 5, 10, 20, 40m height.

C.2 Scope of the near field – far field extrapolation method

The goal of the engineering extrapolation method is to give an indication of the contribution of reflected sound in the far field due to reflections against a NRD under test.

The scope of the extrapolation method is directly linked to the scope of the near field reflection test method described in this standard.

The application of the method is limited to the NRD types and geometries that were used to generate a database of simulated far field reflection data that served as a basis for the development of the extrapolation method.
If a specific NRD design does not fall within the range of types and dimensions used in the simulations it cannot be assessed with the extrapolation method.
Specific Boundary Element Model (BEM) simulations should be carried out for this particular NRD to obtain a reliable estimate of its far field reflection effects.

The extrapolation method estimates the far field reflection contribution within an uncertainty margin relative to the result of a BEM simulation. If an assessment of the far field reflection contribution with a smaller uncertainty is required it is advisable to execute a dedicated BEM simulation for the particular NRD design.

C.3 Basis of the extrapolation method

A full description of scientific basis of the method and its development steps is given in the Final report of QUIESST WP 2 [1].
The basis for the method is formed by two data bases filled with results of numerical simulations.

C.3.1 Near field data base

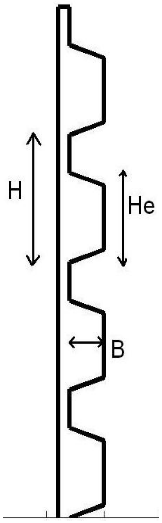
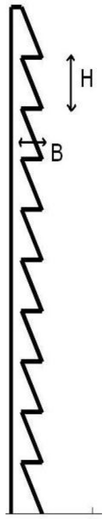
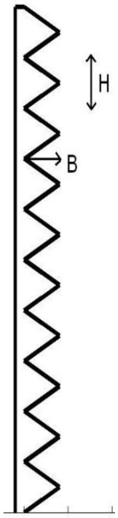
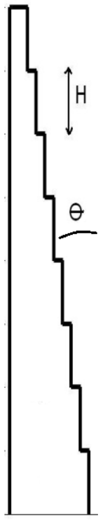
The first database consists of results of simulations of near field reflection tests for a series of NRD variants that represent the majority of NRD designs on the European market.
Five different families of NRD types were selected, each with a range of geometrical variations (see Table C.1).

For each NRD type 3 different types of absorptive material were applied:

1. Rigid: all materials with an acoustically hard surface (100 % reflective; 1 variant)
2. Porous concrete (6 variants)
3. Perforated metallic or plastic cassettes filled with mineral wool (6 variants)

The total number of NRD variants in the near field data base is 1196. For each NRD variant the spectral values of RI_{nf} (near field Reflection Index; see sub clause 5.2) and the corresponding single number rating $DL_{RI\ nf}$ (see sub clause 5.8), averaged over three receiver positions used in the simulation were stored in combination with the material and geometrical parameter values.

Table C.1 - NRD variations

NRD category	 **Flat - tilted**	 **Panes**	 **Sawtooth**	 **Zigzag**	 **Steps**
Geometrical variations	**Angle of inclination** $\theta_{\min} = 70°$ $\theta_{\max} = 90°$ $d\theta = 5°$	**Profile depth** $B_{\min} = 0.05m$ $B_{\max} = 0.15m$ $dB = 0.05m$ **Profile height** $H = 0.1m, 0.25m, 0.5m, 1.0m$ **Ration in/outward** R=20%, 50%, 80%	**Profile depth** $B_{\min} = 0.10m$ $B_{\max} = 0.30m$ **Profile height** $H_{\min} = 0.33m$ $(= 12 elements)$ $H_{\max} = 0.80m$ $(= 5 elements)$	**Profile depth** $B_{\min} = 0.10m$ $B_{\max} = 0.30m$ **Profile height** $H_{\min} = 0.33m$ $(= 12 elements)$ $H_{\max} = 0.80m$ $(= 5 elements)$	**Tilt:** $\theta_{\min} = 0°$ $\theta_{\max} = 15°$ $d\theta = 5°$ **Profile height** $H_{\min} = 0.33m$ $(= 12 elements)$ $H_{\max} = 1.0m$ $(= 4 elements)$
Total number	**5**	**30**	**24**	**24**	**9**

C.3.2 Far field database

The second database contains the results of Boundary Element Model (BEM) simulations of the far field reflection index RI_{ff} values, computed for the same series of NRD variants as the near field data.
In this case the values were computed for the five different receiver positions in the far field, already described in sub clause C.1. For each receiving position also the far field single number indicators $DL_{RI,ff}$ were computed.

C.3.3 Step-wise extrapolation

The extrapolation is carried out in a two-step approach:
1. The result of a near field reflection test of the NRD under test is matched to the best fitting simulated variant in the near field database. The matching procedure uses a pre-selection of possible variants based on the NRD type and the geometrical shape parameters. Then the variant with the most similar material performance is selected by comparison of the near field single number ratings based on the range of 1/3-octave

frequency bands from 100 – 1000 Hz. The material of the selected variant does not have to be of the same type as the material of the tested sample.
The database of near field simulation results is included in a separate sheet of the spread sheet that is a part of this Annex.

2. The material parameters of the selected variant (type of absorption material, flow resistivity and porous layer thickness) are used as input data for the computation of an estimate of the far field effects of the tested NRD sample. This estimate is computed with a polynomial approximation of the contents of the far field database.

The approximation function is a third order polynomial, consisting of a number of terms. Each term consists of a coefficient, variables and exponents belonging to the variables. An example of a third order polynomial, consisting of 10 terms with variables x and y is given in Equation (C.5). The choice for using a third order function, instead of a higher order, is made in order to keep the fit functions as simple and compact as possible.

$$P(x,y) = C_1 \cdot x^3 \cdot y^0 + C_2 \cdot x^0 \cdot y^3 + C_3 \cdot x^2 \cdot y^1 + C_4 \cdot x^1 \cdot y^2 + C_5 \cdot x^2 \cdot y^0 + C_6 \cdot x^0 \cdot y^2 + C_7 \cdot x^1 \cdot y^1 + C_8 \cdot x^1 \cdot y^0 + C_9 \cdot x^0 \cdot y^1 + C_{10} \cdot x^0 \cdot y^0 \quad \text{(C.5)}$$

A different way of notating the polynomial of Equation (C.5) is shown in Table C.2.

Table C.2 - Alternative notation of equation (C.5)

Term	Coefficient	Exponent variable 1	Exponent variable 2
1	C_1	3	0
2	C_2	0	3
3	C_3	2	1
4	C_4	1	2
5	C_5	2	0
6	C_6	0	2
7	C_7	1	1
8	C_8	1	0
9	C_9	0	1
10	C_{10}	0	0

For each NRD type and each material type a separate polynomial function is derived. Dependent of the NRD type the variables used in the polynomials are a selection from the following set:

- Height of the receiver position;
- Inclination angle (ϑ) of the NRD;
- Element height of surface profile (H);
- Element depth of the surface profile (B);
- Ratio of height of protruding part of element to total element height (He/H);
- Number of steps for NRD type “steps” (computed from element height and total NRD height);
- Tangent of the inclination angle for NRD type “steps” (computed from element height and element depth).
- Flow resistivity of porous absorbing materials;
- Layer thickness of porous absorbing materials.

The polynomial approximation offers the possibility to interpolate between the simulated NRD variants.

The polynomial functions used for each of the 15 'NRD type – material' combinations are specified in separate sheets of the pre-programmed Excel spread sheet that is a part of this Annex.

C.4 Uncertainty of the extrapolation method

The extrapolation method is a heuristic method. It is based on an approximation of the data that were computed with numerical simulation models for 1196 barrier variants. The approximations deviate to a certain extent from the original simulated data.

The first step of the approximation process, the matching of the near field test results to the best fitting simulated variant, was tested with the results of the Round Robin Test that was carried out in QUIESST WP 3. It appeared that the differences between the single number ratings of the tests and the single number ratings of the fitted variants were always smaller than 1 dB, except for one very unusual design (absorbing zigzag; see Figure C.2). The differences between simulated and measured results are of the same order of magnitude (or even smaller) as the expanded uncertainty of the reflection test method (see Annex A sub-clause A.4)

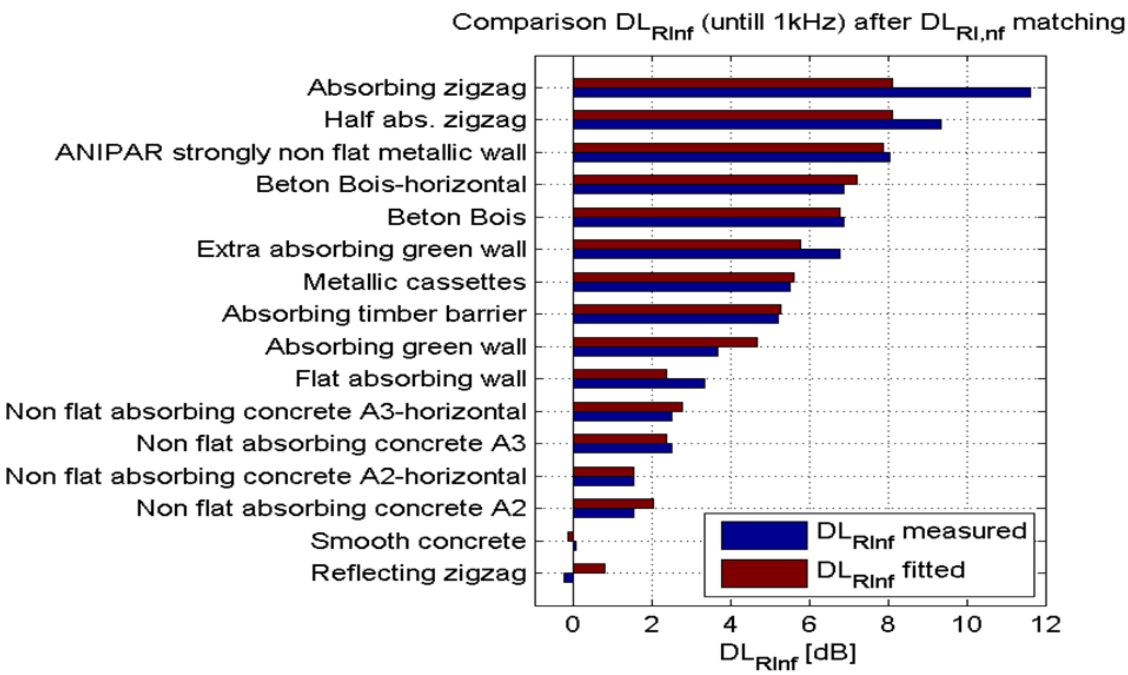
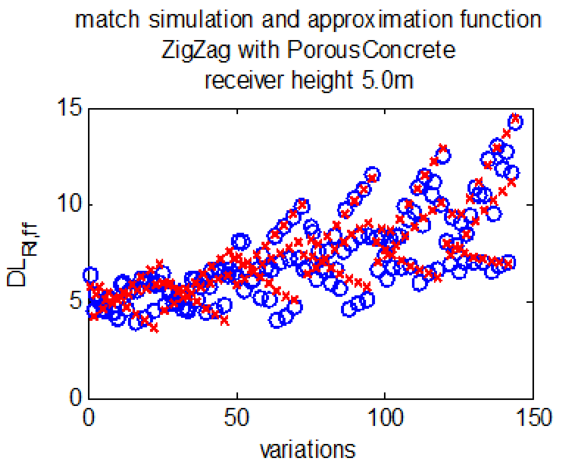


Figure C.2 - Comparison between Round Robin Test results and best fitting simulated variants (based on near field single number rating $DL_{RI,nf}$ in the frequency range 100 - 1000 Hz)

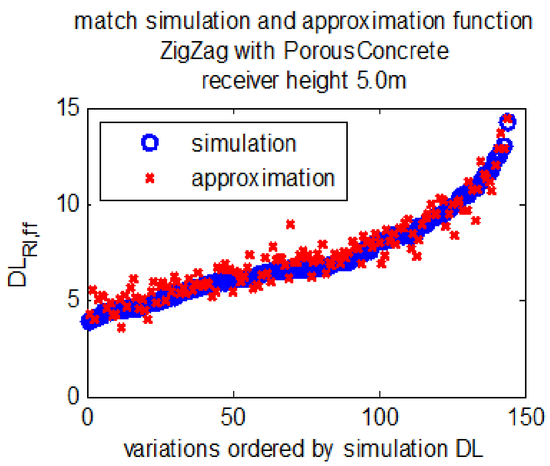
The second step estimates the far field reflection contribution for the best fitting simulated variant. This estimate is executed with the polynomial functions described in sub-clause C.3.3. In order to check the uncertainty of this approximation the estimated values were compared with the original values simulated with BEM for all 1196 barrier variants and 5 receiving positions. Figure C.3 shows a graph of the comparison for one of the barrier types
This comparison showed that 88 % of all the approximated data was within 1 dB of the original simulated values and 99 % was within 2 dB.
From these assessments it may be concluded that both steps of the method have an expanded uncertainty of approximately ±1 dB compared to the measured c.q. simulated

values. The combined expanded uncertainty of the extrapolation method may then be estimated at ±1,4 dB.
For barrier samples with a very high near field single number rating (> 10 dB(A)) the uncertainty of the far field performance estimation may be larger (≤ ± 3 dB).

In this assessment of the estimation uncertainty the far field effects simulated with the BEM model are considered to be the "true" values. Based on experiences in other studies there is a well-founded confidence in the reliability of the BEM simulation method, if it is used for modelling of sound propagation over relatively short distances.
Therefore the engineering extrapolation method derived from the BEM simulation results is presented with confidence and the uncertainty values specified above are seen as realistic estimates.



Results of polynomial approximation sorted in order of geometric variation



Results of polynomial approximation sorted in order of DL

Figure C.3 - Example of fitting performance - zigzag type barrier with porous concrete

C.5 Description and instructions for use of the pre-programmed Excel spread sheet

The description of the extrapolation method in full detail is not given in the text of this Annex, but in the pre-programmed spread sheet that belongs to the Annex. It contains the algorithms and logical decision steps needed to execute the near field matching procedure and the full polynomial functions for all 15 NRD variants have to be applied to estimate the far field reflection performance indicators.

The use of the spread sheet is as follows (see Figure C.4)

1) Fill in at the first line the values of RI averaged over 9 microphone positions, as obtained from the reflection test of the NRD according sub-clause 5.2 of this standard;
2) A graph of the inserted RI data will be shown and the values of the single number ratings $DL_{RI\ nf}$ (for the frequency ranges 100 – 1000 Hz and 100 – 5000 Hz) will appear in the yellow boxes. Check whether the single number rating for the full frequency range (100 – 5000 Hz) corresponds to the DL_{RI} value obtained from the reflection test according to sub-clause 5.8 of this standard;
3) Choose from the drop-down list at line 3) the NRD type that corresponds to the tested NRD using the figure to the right;

Note
Most NRD's with porous granular material, like porous concrete, that have a grooved or corrugated surface should be characterised as a "Panes" type of NRD. The ZigZag type is only applicable for larger surface shapes with a specific triangular cross section.

4) Choose from the drop down lists the best matching values of Theta, H, B and /or the ratio He/H in the white boxes, as applicable for the NRD sample in question;
5) At line 5) the best fitting variant from the near field data base will appear in the yellow boxes as a result of the near field matching procedure. The parameters of the best fitting variant are now being used for the far field extrapolation;
6) At line 6) the final results of the far field approximation will appear in the yellow boxes. The results are:

$DL_{RI,\,ff,\,LR}$ the single number rating of the far field reflection indices for low rise buildings

$DL_{RI,\,ff,\,HR}$ the single number rating of the far field reflection indices for high rise buildings

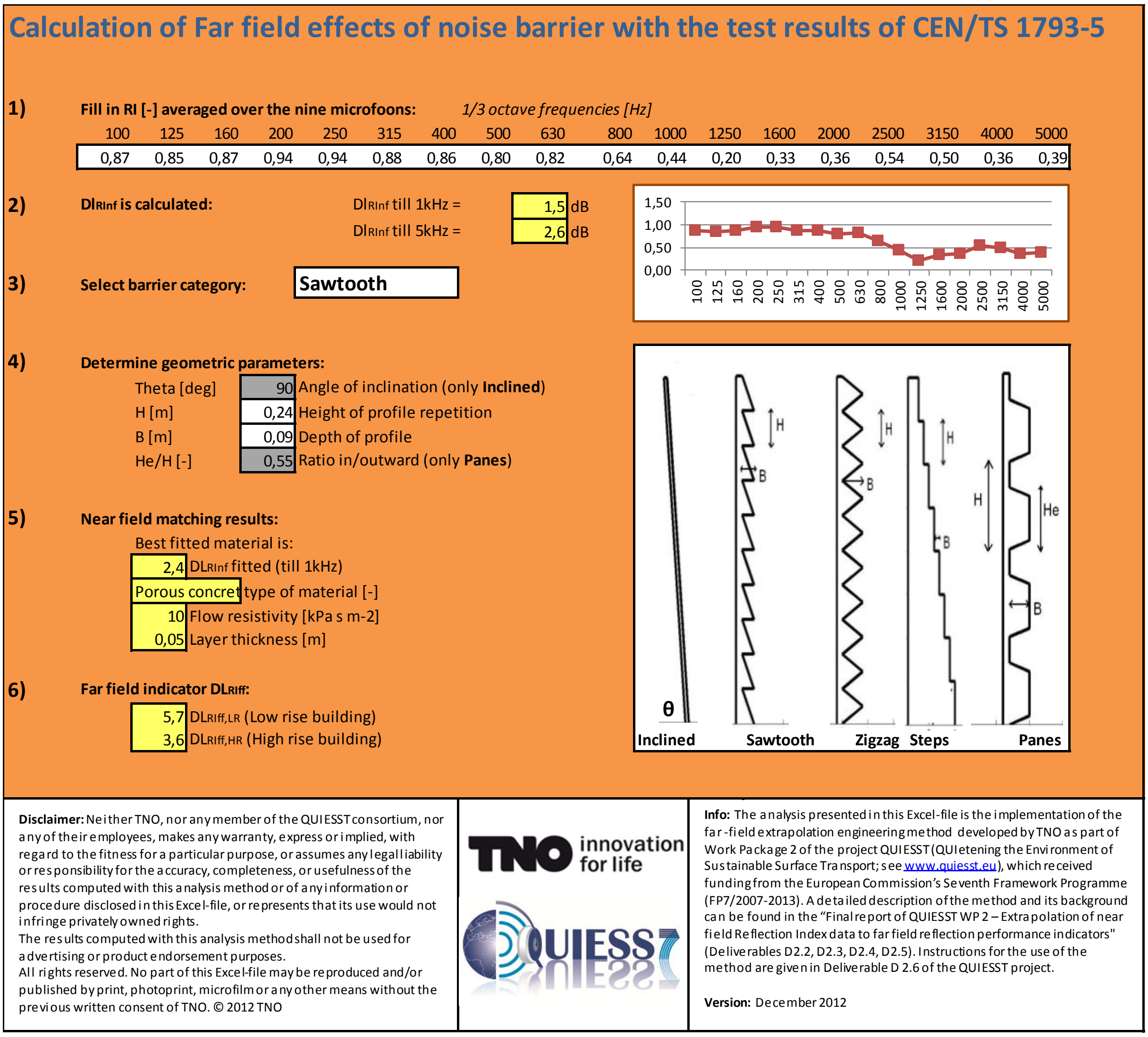


Figure C.4 - Home sheet of the Excel spread sheet that shall be used for the computation of the far field reflection performance indicators.

C.6 References

[1] Lutgendorf, D., F. de Roo, P.W. Wessels, F.J.M. van der Eerden, B. Bragado Perez, P. Jean, R. Wehr, *Final report of QUIESST WP 2 – Extrapolation of near field Reflection Index data to far field reflection performance indicators,* QUIESST Deliverables D2.2, D2.3, D2.4 and D2.5, TNO, The Hague, 17 December 2012.