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THE OPTIMISATION OF POROUS ASPHALT ROAD SURFACES TO MAXIMISE SOUND ABSORPTION

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1. INTRODUCTION

In a recent study[1] commissioned by the EU an estimation was made of the extent to which noise pollution from different sources affects the people in Europe. From this it appears that road-traffic noise is by far the most important source of environmental noise pollution as from the 210 million people in Europe who feel considerably annoyed by environmental noise, some 125 million attribute this annoyance to road traffic noise. This not only justifies but also renders imperative that the highest priority be given to measures that reduce the noise from this source. As the highway is an integral part of the environment in urban and rural areas there is a need, for engineers to have regard not only to their role in maintaining the highway network and keeping traffic flowing, but also in managing the environment of which the highway is a part.

2. TRAFFIC NOISE

2.1 Sources of Vehicle Noise

Traffic noise results from the collective contribution of noise produced by individual motor vehicles. The vehicles vary enormously depending upon their type and mode of operation. The noise produced varies in pitch and loudness and continuously fluctuates. As traffic noise is generated from the entire network of roads forming the matrix of an urban environment it impacts residents to a greater or lesser degree everywhere. The typical effects of traffic noise will be annoyance and interference with life in and around the home.

The actual sources of vehicle noise are identified in Figure 1. The relative importance of these sources depends on the type of vehicle and the operating conditions.[2] In recent years priorities have shifted from emission control of the vehicles as far as their engine and exhaust noise is concerned, to the control of tyre/road noise. This has occurred due to the reduction of engine and exhaust noise, mainly as a result of the gradual tightening of noise limits imposed by the EC Directives. Tyre/road noise, therefore has become more important and is now the dominant traffic noise source particularly in free-flowing traffic at speeds of above 40-50 km/h.[1]

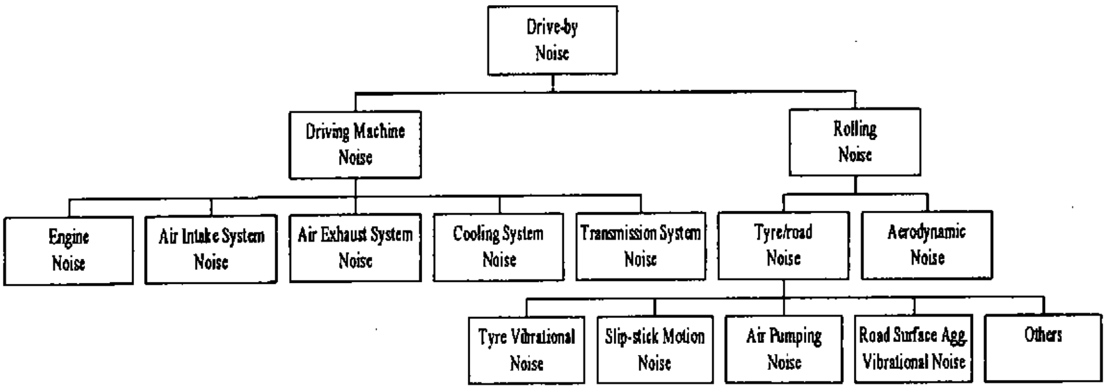

Figure 1 Noise Generation Factors of Vehicles[3]

2.2 Parameters affecting Rolling Noise

There are numerous factors which affect the production of 'rolling' noise, for example speed and weight of vehicle, wear, tread and structure of the tyre, the actual road surface and the presence of surface water. However, the range of noise levels for the different surfaces is considerably greater than the small differences resulting from the changes in tread pattern. This is one of the reasons why it is generally considered that there is greater scope for reducing tyre/surface noise by redesign of the road surface than by design of the tyre[4].

The main characteristics determining noisiness of road surfaces are geometrical features, acoustical and mechanical properties of the pavement.[5] Two independent generation processes have been identified; one in the low frequency range (<1000Hz) is radial roughness induced vibration; the other in the high frequency range is identified as air-pumping.[6] It has been shown that the noise level increases with increasing texture depth. However at a certain point this increase ceases, due to the tyre being unable to form a seal down to the base of the aggregate, hence reduced air pumping.[7]

In addition to reduced levels of noise being produced by road surfaces with optimised textures some actually attenuate noise levels by an absorptive mechanism. In order to achieve the greatest possible reduction in drive-by noise, the sound absorption of the road must be optimal, that is the maximum sound absorption of the road must be as high as possible in the frequency range which is most significant for road traffic noise.

Models characterising the acoustic performance of porous asphalt road surfaces have previously been formulated by others such as Attenborough & Howorth and Berengier et al [8] These were based on four parameters : Porosity (volume of connected air pores to the total volume), Tortuosity (measure of the 'straightness' of the porous channels), Air Flow Resistivity (frictional retardation of flow through the pores) and Thickness of the sample. Research at the Transport & Road Research Centre, University of Ulster, aims to establish the relationship between these four parameters and the grading of the road surface mix.

3. Investigative Methods

3.1 Porous Asphalt Samples

In order to investigate the effect of stone size on porosity, tortuosity, air flow resistance and sound absorption, Marshall moulds were made using aggregates classified as 100% cubic[9], single size graded 10 mm, 14 mm and 20 mm aggregates. The surface area of the aggregate was estimated by coating it with an oil and measuring the quantity of oil required for a complete coating. This gave an indication of the quantity of bitumen required to give the aggregate a light uniform coating. 100 pen bitumen was added and the aggregate used was Andesitic tuff. In order to investigate the role the shape of the aggregate plays in the sound absorptive properties of porous asphalt, 10 mm, 14 mm & 20 mm moulds were also made up using aggregates classified as 100 % 'flaky'.[9]

3.1.1 Sound Absorption Testing

Sound absorption testing was carried out using the impedance tube method[10] on the moulds. The airflow resistivity of the samples was determined using the Direct airflow method.[11] Tortuosity was measured by an adapted method developed by Champoux.[12]

3.1.2 Phenomenological Model Verification

A phenomenological model has been proposed by Hamet which models the sound absorption of a surface, given the tortuosity, porosity , air flow resistivity and the sample thickness. In order to verify the model apparatus was assembled to measure these parameters. Using these results and then measuring the sound absorption coefficient of the surfaces the model was verified. The model was then used to investigate the effects of varying these four parameters on the sound absorption performance.

3.2 Pass-by Measurements

Linear frequency spectra were obtained of traffic noise from the roadside at four sites under wet and dry conditions. The sites were surfaced with hot rolled asphalt and porous asphalts.

4. RESULTS

	Cubes 10	Cubes 14	Cubes20
Porosity	0.303	0.346	0.365
Tortuosity	1.56	1.59	1.54
Airflow Resistivity (Ns/m^4)	730	350	215
Layer Thickness (m)	0.060	0.061	0.062

Table 1 Porosity, tortuosity, airflow resistivity and layer thicknesses of porous asphalt moulds made using 100 % cubic 10, 14 & 20 mm stones

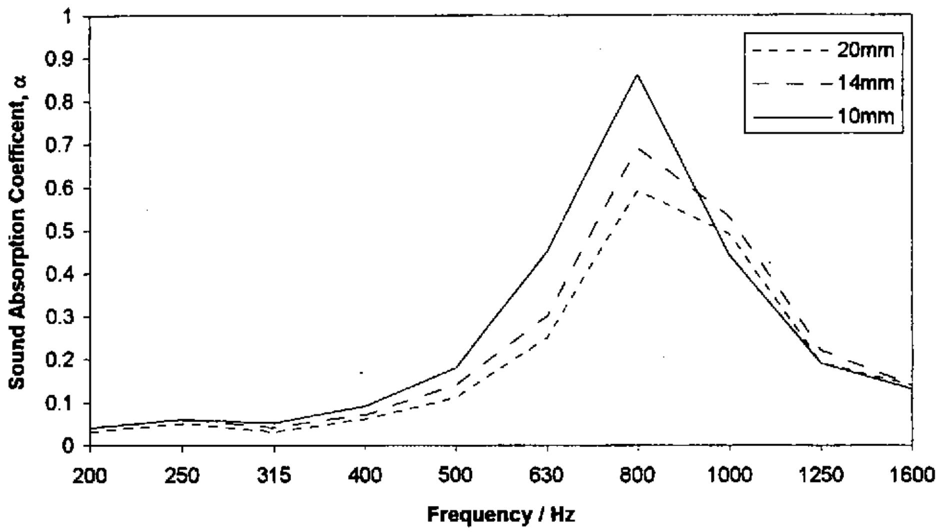

Figure 2 Sound absorption coefficient of single size 10, 14 & 20mm 'Cubic' porous asphalt

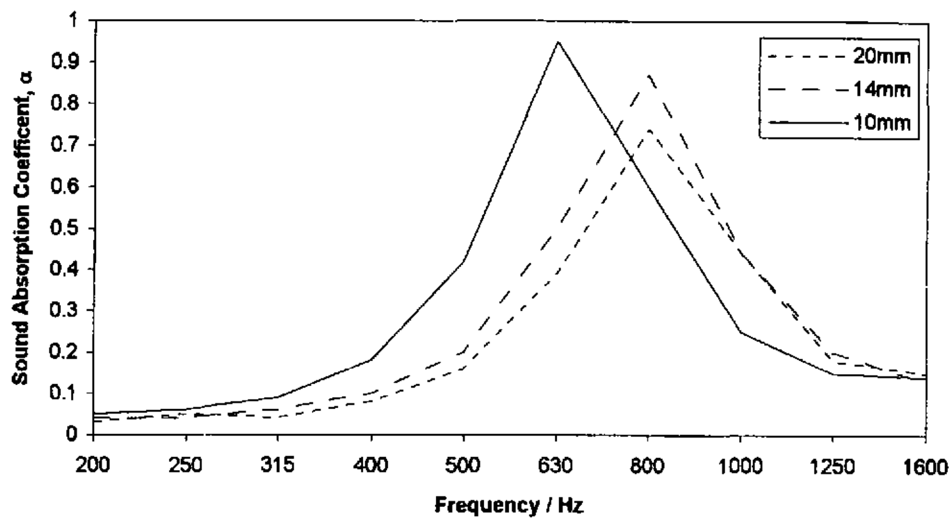

Figure 3 Sound absorption coefficient of single size 10, 14 & 20mm 'Flaky' porous asphalt

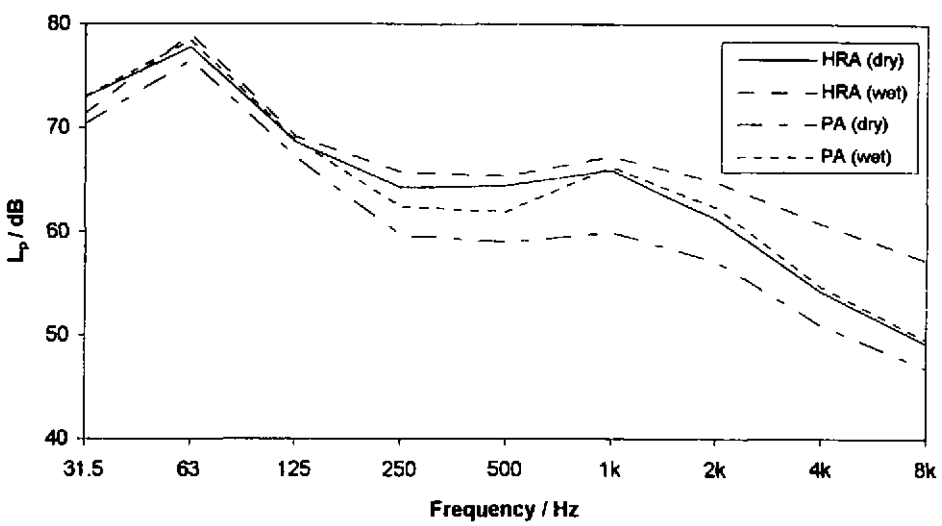

Figure 4 Sound pressure levels of roadside traffic noise on HRA and PA (20 mm) surfaces under wet and dry conditions

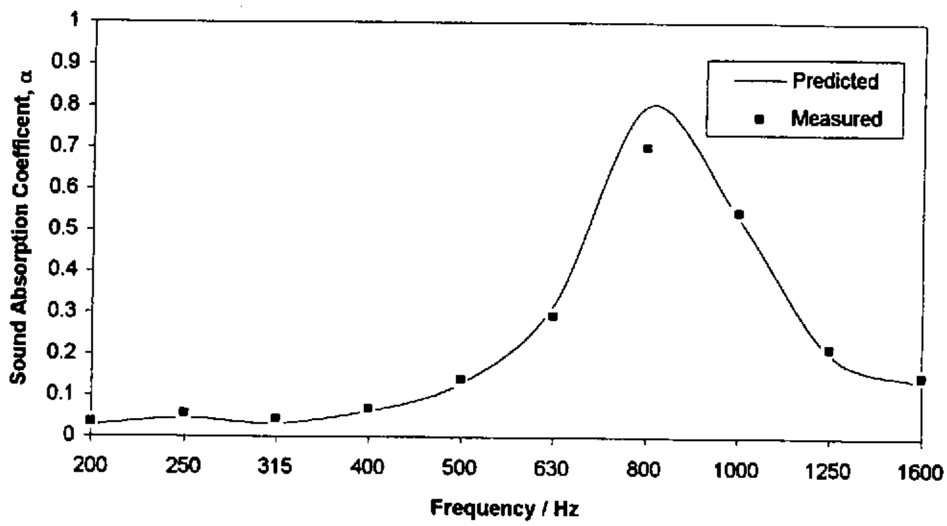

Figure 5 Verification chart showing measured and predicted sound absorption values of a 'cubic' 14 mm sample

5. DISCUSSION

It can be seen from Figure 2 that the highest sound absorption coefficient occurs with the 10 mm 'cubic' aggregates. With all the 'cubic' aggregates the peak sound absorption coefficient has occurred at 800 Hz. This is significant because when Figure 4 is examined it can be seen that aside from the peak at 63 Hz, attributable to engine noise, the most noise is produced in the frequency range 500 - 2000 Hz. The human ear is most sensitive in the high frequency region, therefore reduction in this area is most valuable. The sound absorption coefficient of the 14 mm samples was not as high as the 10 mm but higher than the 20 mm. It should also be noted that although 10 mm produced the highest sound absorption peak, it doesn't attenuate frequencies >800 Hz as well as the other two.

Figure 3 shows how the 'flaky' aggregate sound absorption coefficient varies with size. The same ranking is found as with the 'cubic' aggregate, with 10 mm performing best. However the frequency at which the maximum absorption of the 10 mm aggregate occurs has shifted to 630 Hz, with less absorption occurring at frequencies over 630 Hz than with the 14 and 20 mm aggregate.

Figure 4 highlights how porous asphalt has reduced road traffic noise levels from those produced by hot rolled asphalt under both wet and dry conditions. In the dry it can be seen that there is a reduction in low frequency noise, due to reduced vibrations by the optimised road surface and also in the high frequencies due to reduced air pumping and absorption of the resulting noise. Under wet conditions it can be seen that the porous asphalt noise levels are much lower in the high frequency region than those of hot rolled asphalt, due to the drainage capability of porous asphalt curtailing splash noise.

Figure 5 shows measured and predicted values of sound absorption. It can be seen that there is good correlation, therefore the model may be incorporated into further research work.

6. CONCLUSIONS

1. Research at UUJ shows that road traffic noise is dependent to an extent on the road surface.
2. Equipment was successfully set up to measure porosity, tortuosity and airflow resistivity an sound absorption leading to the verification of the phenomenological model.
3. Porosity, tortuosity, and air flow resistivity are dependent on the size and shape of aggregate used.
4. The sound absorption coefficient is dependent on the porosity, tortuosity and air flow resistivity.
5. As the aggregate size decreases, so the absorption coefficient peak increases.
6. 'Flaky' aggregate absorbs marginally more noise than 'cubic' aggregate

7. FURTHER WORK

From data obtained both from previous and future experiments, it should be possible to establish the link between the parameters tortuosity, porosity, air flow resistivity, layer thickness and mix characteristics, such as % bitumen, % fibres, stone shape and grading. This will hopefully lead to the formulation of a mathematical model to predict sound absorption when the mix characteristics are known. The purpose of such a model would be to optimise the acoustical properties of a surface by altering the mix within certain limits which ensure that other road properties such as those relating to safety, longevity and costs are preserved.

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POSSIBLE CHANGES TO THE REGULATORY CONTROLS FOR PROTECTING NEW DWELLINGS FROM EXTERNAL NOISE

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1. INTRODUCTION

Bickerdike Allen Partners (BAP) have recently undertaken a study on behalf of the Department of the Environment, Transport and the Regions to investigate the feasibility of proposed controls under the Building Regulations for protecting new dwellings from external noise and to develop initial guidance on sound insulation measures. The results of BAP's work are summarised here. The views expressed are those of the authors and do not represent the Department's policy.

Currently, the Local Planning Authority decides when it is necessary to protect dwellings from noise and will impose appropriate noise control measures through the planning system. Noise control measures may include site layout and screening and/or measures to insulate the building envelope.

Draft Proposals for alternative controls were developed during a consultation exercise, conducted for the Department by Wimtec Environmental. Under the Draft Proposals, the sound insulation of the building envelope would be controlled by the Building Regulations. It would be overseen by Building Control (either the Local Authority Building Control or an Approved Inspector), who have a general duty to see that building work complies with these Regulations. The responsibility for planning measures to control noise – i.e. site planning and screening – would remain with the Local Planning Authority. There would, therefore, be a transfer of responsibility for building envelope sound insulation matters from the Local Planning Authority to Building Control. This would facilitate co-ordinated control of sound insulation, ventilation and thermal insulation. Building Control already have a responsibility with regard to the implementation of Part E of the Building Regulations, which covers the sound insulation of separating walls and separating floors.

The purpose of BAP's study was to examine the feasibility of the transfer described above and to develop draft guidance for Building Control purposes.

2. STAGE 1 OF THE STUDY

2.1 Current Controls and Initial Interviews

The guidelines and regulations which apply to the current system of control, which is operated by Local Planning Authorities, have been reviewed. Local Planning Authorities are guided by Planning Policy Guidance PPG 24, Planning and Noise[1] in their consideration of applications for residential development near transport-related noise sources. This document classifies sites in terms of Noise Exposure Categories, which are defined in the PPG. They may refer to BS 8233: 1987[2] in relation to internal noise limits and BS 4142:1997[3] in relation to the assessment of industrial noise.

Views were sought from the Department and interviews were held with a Planner, Environmental Health Officer, Planning Consultant, Building Control Officer and an Approved Inspector. The information provided and views expressed were used to develop a set of Draft Proposals.

2.2 The Draft Proposals

Under the Draft Proposals, the powers of the local planning authority would be unchanged. They would continue to take account of noise in their consideration of planning applications and to use their powers to refuse permission or to attach conditions, where appropriate. Relevant conditions might cover noise control by planning measures, such the position and orientation of the dwellings with respect to the dominant noise source, and site screening.

The sound insulation of the building envelope would be covered by the Building Regulations. The planners should be satisfied by the developer's submission that the exposure of the proposed dwelling(s) to noise is such that it is reasonably practicable for the developer to meet these requirements. They need not consider the details of construction unless they impact on other planning considerations (for example, the design of new windows may be a planning consideration in a conservation area).

Where all or part of the site is determined to be at or above a threshold level (PPG24[1] Noise Exposure Category B), the Building Regulations procedures would be triggered. The Developer would require Building Regulations approval for the sound insulation of the building envelope. The Regulations would require a reasonable minimum standard of sound insulation to be provided. Approved Document E[4] would be extended to provide practical guidance.

2.3 Interviews and Case Studies

All those initially interviewed considered the Draft Proposals to be feasible, subject to resolving detailed matters. These matters included the need for training Building Control staff, the interface between the Local Planning Authority and Building Control, the information required by Building Control and computational methods to be used, the timing of construction works and the role of post-construction testing, if any. The main advantage of the Draft Proposals was considered to be that Building Control staff visit sites and are better placed than Planning staff to see that sound insulation works are properly implemented, along with ventilation measures if appropriate.

On the basis of the developed Draft Proposals, Planning and Building Control details were collected for eleven case studies of new dwellings planned and constructed on noise-affected sites in various parts of England and Wales. The views of contributing Planning and Building Control staff were obtained and the case study details analysed. All the Planning Officers and Building Control Officers and two Approved Inspectors who contributed to the case studies considered that the Draft Proposals would have been feasible for their project and saw benefits. The remaining Approved Inspectors did not express a view as to feasibility.

The case studies highlight some disadvantages of the present system. They indicate that the present procedures do not result in the building envelope noise issues being resolved before construction works start on site. The sound insulation requirements are decided locally and there is variation between authorities. Once approval is given, planners tend not to follow up the matter to ensure that agreed specifications are complied with and that the works are carried out to an appropriate standard.

Under the Draft Proposals, the sound insulation requirements would be explained in an Approved Document to the Building Regulations, which apply nationally across England and Wales, and the provisions would be enforced by Building Control. This would effectively overcome some of the disadvantages of the present procedures, but would not prevent developers from commencing construction work at their own risk under the Building Notice procedure.

BAP's Stage 1 Report concluded that the Draft Proposals are feasible and that they would be beneficial in ensuring that appropriate sound insulation schemes are developed and that they are properly implemented.

3. STAGE 2 OF THE STUDY

Having concluded that the Draft Proposals are feasible, BAP moved on to Stage 2 of the study, the object of which was to formulate a basis for guidance to developers and Building Control and to prepare a first draft of this guidance.

3.1 Basis for the Requirement

It is anticipated that the requirement of the Building Regulations would be that the building envelope of a dwelling should provide reasonable resistance to the transmission of airborne sound. This is similar to the basis used in the 1991 Regulations for separating walls and separating floors and stairs.

In determining the sound insulation requirements of the building envelope of a dwelling, it is necessary to consider both the exposure of the building to noise and the acceptable noise levels inside the building. The sound insulation requirements of the building envelope can be derived from this information.

It might be thought that limiting the acceptable noise inside the building could be a suitable basis for the Building Regulations requirement. This is considered inappropriate for the following reasons:

1. If testing for compliance, it will not normally be reasonably practicable to measure the internal level in a completed dwelling over a sufficiently long period to establish the daytime and night time internal noise level. This is because of fluctuations in the external level over the day and night period and possible interference from noise sources inside the building or on site.

2. There are, in any case, no British or International Standards governing such noise measurements inside buildings. In contrast, the sound insulation of the building envelope can be measured in accordance with BS EN ISO 140-5: 1998[5].

3. The external noise conditions at the time of completion of the dwelling may not correspond to the levels predicted at the time of design (for example, because a predicted growth in traffic flows has yet to occur).

4. The noise levels defining the Noise Exposure Categories in PPG24 are source-specific. Consequently, for a given NEC, the internal noise level will vary somewhat according to source type.

5. There is a need for a short calculation method in the Approved Document to establish whether or not a given building envelope scheme will meet the requirements of the Regulations. This would use single figure descriptors based on model noise spectra and would be intrinsically less accurate than more rigorous methods of calculation. Unless a large safety margin is built into the calculation method, it is inevitable that a given internal noise limit will be exceeded in a minority of cases where the method has been properly applied.

6. The Building Control system has no influence over the external noise environment. It can only control the design and construction of buildings.

It is therefore considered that target internal noise levels should not be stated explicitly in the Approved Document.

3.2 Basis for a Numerical Performance Standard

The most appropriate basis for numerical sound insulation targets is considered to be the standardized level difference, $D_{2m,nT}$, defined in BS EN ISO 140-5:1998, which is the level difference, in decibels, between the outdoor sound pressure level 2 m in front of the building envelope and the space-time averaged sound pressure level in the receiving room, standardized to a reference reverberation time of 0.5 seconds.

The proposed objective is that the standardized level difference, based on the A-weighted sound pressure levels outside and inside a furnished room, should achieve a given value.

If a formal method for measuring sound insulation was required for Regulation purposes, it would be necessary to measure the standardized level difference over the one-third octave band frequency range, 100 – 3150 Hz in accordance with BS EN ISO 140-5. A single-figure, weighted result ($D_{2m,nT,w}$) would then be obtained according to BS EN ISO 717-1[6]. The spectrum adaptation terms, C and C_{tr} would also be computed according to this standard, and these values used to adjust the result to represent the reference spectrum which best matches the predominant noise source. This methodology eliminates variations between sites which would arise due to the differing spectral content of the prevailing noise source at each site. Consequently, by using a reference spectrum, a given building envelope construction should be expected to achieve similar results on different sites.

According to BS EN ISO 140-5, the standardized level difference can be obtained using a loudspeaker source, by measuring road traffic noise, or estimated using aircraft or railway traffic noise. The aircraft noise and railway traffic noise methods, given in Annex D to the standard, provide estimates only. It is proposed that these methods should be considered acceptable for Regulations purposes, as they are the only feasible methods to obtain the global result in situations where more than one building envelope element (façade or roof) is exposed to significant noise from the prevailing source.

3.3 Proposed Contents of the Approved Document

Noise Exposure

Where a site noise survey has been carried out, the Noise Exposure Category of the dwelling should be determined. This would be based on the Noise Exposure Categories given in PPG24, but measurements made at a height between 1.2 and 1.5 m above the ground would be adjusted, as necessary to obtain free-field levels at the position of affected façade(s) and/or roof.

Where no measurements are available, and the site is considered likely to fall in Noise Exposure Category A, the Approved Document would provide a series of checks which can be made, such as distances from different categories of roads, railways and airports and the presence of screening. The developer would make a case to Building Control on this basis. If Building Control consider that the criteria are met, the site would be deemed to be in NEC A. If not, a noise survey would become necessary.

The Provisions

The Approved Document would show three main ways of complying with the requirement by:

a Adopting one of the combinations of more widely used building envelope constructions described in the Approved Document for use in specific noise exposure categories.

b Submitting a calculation showing that the proposed combination of building envelope constructions will meet given numerical sound insulation requirements. Two calculation methods would be given. A short, approximate, method would be described which does not require special expertise to complete, but will tend to underestimate the potential sound insulation of the building envelope. A more accurate method would also be given (based on pr EN 12354-3[7]) which may require more specialised knowledge to complete.

c Providing evidence of field testing carried out on similar housing elsewhere which achieved the numerical sound insulation requirements which apply to the site currently under consideration.

These provisions would relate to the sound insulation provided by the building envelope when windows are closed and background ventilation is provided, as required by Part F of the Regulations.

In order to prevent unacceptable noise conditions arising when windows are opened for rapid ventilation, an alternative means of ventilation would be required above prescribed external noise levels.

For example, sound-attenuated rapid ventilation could be required in all habitable rooms exposed externally to a given level (or Noise Exposure Category), during the daytime period. In the case of bedrooms the requirement could also be related to the night time exposure.

The method of rapid ventilation should provide sufficient ventilation to meet the requirements of Approved Document F[8]. The sound attenuation provided should be sufficient to allow the sound insulation targets described in Approved Document E to be achieved.

Acceptable Constructions

Examples of acceptable constructions would be given which would satisfy the requirements when the dwelling is in Noise Exposure Categories B and C. The Approved Document specifications would be given for the wall, window, roof and ventilator.

Guidance would be given on the design and detailing of sound insulating elements to enable them to achieve their potential sound insulation.

Numerical Provisions

Numerical performance requirements would be expressed in terms of the spectrum-adapted weighted standardized level difference, $D_{2m,nTw,Cj}$, where C_j may be C_{tr} (a typical road traffic frequency spectrum) or C (a flat frequency spectrum), as defined in BS EN ISO 717-1. The Approved Document would specify which spectrum adaptation is to apply.

The numerical performance requirements for habitable rooms would be obtained by subtracting a fixed number (based on the implied internal noise limits) from the daytime free-field noise level at the position of the most exposed part of the building envelope. For bedrooms, another fixed number would be subtracted from the night time free-field noise level. (In the case of the latter, the higher of the two results would be treated as the numerical performance requirement).

Calculation Methods

The building control assessment would be made on the basis of the most exposed habitable room(s) on each façade (or under each roof) exposed at Noise Exposure Category B or higher. On small or simple developments, there may be as few as one or two rooms to consider. More rooms would need to be considered where the developer wishes to tailor the sound insulation design to closely match the distribution of noise levels across the site.

In order to carry out the short calculation method, to be given in the Approved Document, the developer would need to provide the following information:

For each external component of the building envelope (wall, window, roof, door):

A physical description of the component (composition, thickness, air cavity width, mass etc)	
The area of the component	m^2
The external free-field noise level incident at the component. (In the case of industrial noise, the BS4142 rating level, adjusted to include any tonality/ impulsivity correction)	dB $L_{Aeq,T}$
The weighted sound reduction index of the component, $R_w(C;C_{tr})$ measured according to BS EN ISO 140-3[9] and rated according to BS EN ISO 717-1	dB

For a ventilator:

The weighted element normalized level difference, $D_{n,ew}(C;C_{tr})$ measured according to BS EN 20140-10[10] and rated according to BS EN ISO 717-1	dB

The volume of the room under consideration; m^3

The Approved Document would contain a model calculation form and nomograms to aid calculation. Sound insulation data for typical building components would be included in a table.

For developers or Building Control Officers wishing to carry out octave band or one-third octave band calculations, according to pr EN 12354-3, details of the calculation method and typical data could be provided in an Appendix to the Approved Document.

Field Testing of the Building Envelope

The Approved Document could give details of the relevant test standards and nomenclature to be used. Where testing has been carried out on a similar construction, guidance would be given on the physical features which should be similar and on the number of sets of test results to be obtained as evidence of satisfactory performance.

4. SUMMARY

The study indicates that it would be feasible to adopt alternative controls for protecting new dwellings from external noise and that there would be some benefit from this. The initial work on the practical aspects indicates that there are suitable test and calculation methods. A simplified method of calculation has been proposed which would make the implementation of Regulations accessible to non-experts.

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