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information paper

Rain noise from glazed and lightweight roofing

IP 2/06

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BRE Environment

This paper is intended to help designers to assess the likely effect of rain noise from lightweight roofs and roof elements on the indoor ambient noise levels in rooms. It contains results from measurements of the sound intensity levels caused by artificial heavy rainfall on roof glazing, polycarbonate roofing and ETFE roofing, the latter with and without rain suppressors. The measured sound intensity data allow comparison of products and estimation of the reverberant sound pressure level in a room due to rain noise.

The Department for Education and Skills (DfES) design guide on school acoustics, Building Bulletin 93 (BB93[1]), sets out the performance standards for the acoustics of new school buildings, and one of these performance standards is the indoor ambient noise level in unoccupied spaces. This noise level excludes contributions from rain noise, but the guidance states that it is essential that rain noise is considered in the design of lightweight roofs and rooflights as it can significantly increase the indoor ambient noise level. The intention is that in the future, consideration will be given to including a performance standard for rain noise in BB93. Until this time, it is appropriate for design teams to provide evidence to the Building Control Body that the roof has been designed to minimise rain noise. So the DfES commissioned BRE to carry out sound intensity measurements of rain noise from roof glazing, polycarbonate roofing and ETFE roofing in the BRE Rain Noise Laboratory.

In design work, it is the sound pressure level in the room due to rainfall on the roof or roof element that is of primary interest. This paper shows how rain noise from roofs and roof elements is described and briefly explains why the preferred type of roof element excitation is used for laboratory measurements. The full report[2] containing the data from the measurements with the four types of roof element is on BRE's website.

Rain noise: measurement standard

At the time of writing, the ISO Standard for the measurement of rain noise in the laboratory is at the drafting stage. The current draft is ISO/CD 140-18 (ISO TC43/SC2 N 0751)[3].

The measurement of rain noise radiated by a roof element is quoted in terms of the sound intensity level L_I, in dB re 10^{-12} W/m^2. This can be either calculated from sound pressure level measurements in a test room beneath the roof element, or measured directly beneath the roof element using a sound intensity probe. For this

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project, a sound intensity probe was used to measure the radiated sound intensity in accordance with BS EN ISO 15186-1:2003[4].

The draft rain noise standard describes two types of artificial rainfall that can be used: Intense and Heavy. The artificial rainfall parameters that affect the noise generated by roof elements are controlled in the laboratory and are described in Table 1. At present, the intention is that Heavy rainfall shall be mandatory for the comparison of products, but that other types of artificial rainfall such as Intense rain could also be measured using the same measurement set-up and procedures described in the Standard.

Table 1 Parameters for artificial rainfall from ISO/CD 140-18 (ISO TC43/SC2 N 0751)[3]

Rainfall type	Rainfall rate (mm/h)	Volume median drop diameter (mm)	Fall velocity (m/s)
Intense	15	2	4
Heavy	40	5	7

Unlike the artificial rain defined in the Standard, real rainfall consists of drops of different sizes where the drop size depends on rainfall intensity as well as on temperature and humidity. In temperate climates such as the UK, the upper size limit for rain drops is 5 to 6 mm. Above this size the drops break up into smaller drops. In tropical climates, where the temperature and humidity are higher, larger drop sizes can occur. Rainfall data based on meteorological statistics are often presented in the form of the maximum amount of rain that will fall within a specified time period and with a specified probability of occurrence, often described as the return period. A rainfall rate of 40 mm/h has a return period of about 50 years, and a rate of 15 mm/h has a return period of about 2 years.

During a rain storm the rainfall rate is rarely constant, with the most intense rain falling for only a few minutes followed by more gentle rain. Even when the rainfall rate is approximately constant, the short-term intensity will vary because the larger drops will fall fastest.

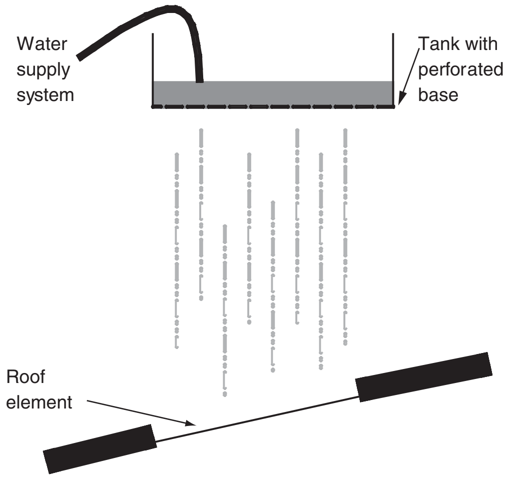

Figure 1 Schematic diagram of test set-up

In this project, measurements were taken using Heavy rainfall. The main reason for choosing Heavy rainfall is that previous experience has shown that it can be difficult to take measurements using lighter rainfall on some roofs because the levels of radiated sound are often too low to allow the measurement of all frequencies between 100 Hz and 3.15 kHz. Another advantage of using Heavy rainfall is that as manufacturers begin to publish measured data in the coming years, these can be compared with the results from this project.

A diagram of the test set-up is shown in Figure 1.

Measurements were taken on:

- 25 mm thick polycarbonate sheet – five layers (3.4 kg/m^2)
- 6–12–6.4 (laminate) glazing (6 mm toughened glass, 12 mm air space, 6.4 mm laminate glass)
- ETFE pillow: 150 micron layer taped to a 50 micron layer, air gap (200 mm cushion dip), 150 micron layer (air pressure = 180 Pa) – with and without rain suppressors Types 1 and 2

Further details of the manufacturers of the roof elements and test set-up are contained in the full report[2].

Findings

To allow comparison of the different test elements, the sound intensity levels in third-octave bands between 100 Hz and 5 kHz are shown in Figure 2. For the 6–12–6.4 glazing and the ETFE without a rain suppressor, it was not possible to measure the 100 Hz third-octave band because the sound intensity measurements did not meet the criteria in BS EN ISO 15186-1[4].

The tabulated measurement data are contained in the full report[2]. The main findings were as follows.

- The 6-12-6.4 (laminate) glazing had the lowest sound intensity levels.
- The ETFE roof element without a rain suppressor had the highest sound intensity levels.
- The polycarbonate roof element radiated the highest sound intensity levels above 1.6 kHz.
- Use of the rain suppressors Types 1 and 2 with the ETFE roof element resulted in significant reductions in the sound intensity level.
- Using the A-weighted sound intensity levels, the rank order from the highest to the lowest levels of rain noise was:
  1 ETFE roof element
  2 Polycarbonate roof element
  3 ETFE with rain suppressor Type 1
  4 ETFE with rain suppressor Type 2
  5 6–12–6.4 (laminate) glazing

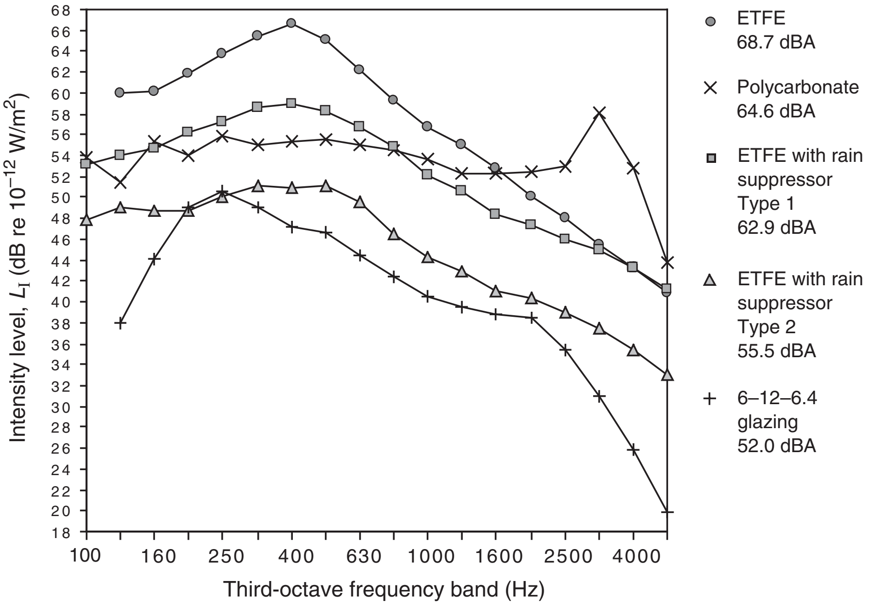

Figure 2 Measured sound intensity levels for the different roof elements

Using laboratory data to calculate the sound pressure level in rooms

In design work it is the sound pressure level due to rainfall in the room beneath the roof element that is of primary interest. In this case the measured third-octave band intensity levels, L_I, for the roof element need to be converted into sound pressure levels for a specific room. To make this calculation it is convenient to assume that the roof element radiates sound into a reverberant room, so that the reverberant sound pressure level is the relevant parameter. This is appropriate for most practical applications.

The parameters that describe the artificial rain used in the laboratory are: the excitation area, the median drop diameter, raindrop velocity on impact, and the rainfall rate. The rainfall rate (also referred to as the rain intensity) in mm/h is the height of rainwater accumulated in one hour on a horizontal surface without a drain. In the BRE laboratory this rate is calculated assuming the rain to be falling on an area of 1 m^2. Therefore to calculate the rain noise *in situ*, the measured intensity levels from the laboratory test need to be converted to the situation where the rain falls over the entire area of the test specimen.

Step 1

The intensity level L_I from the laboratory test is converted to an intensity level $L_{I(S)}$ using Equation 1, where the subscript '(S)' indicates that there is excitation over the entire area of the test specimen (S is in m^2). Note that the reference value (1 m^2) in the denominator is not the excitation area but relates to the reference area for the calculated rainfall rate. (The Heavy rain tank used in the tests gives 1 m^2 coverage when the test specimen is at an angle of 30°.)

$$L_{I(S)} = L_I + 10 \log (S/1\ \text{m}^2) \qquad \ldots(1)$$

Step 2

The next step is to calculate the sound power for the roof element when installed *in situ*. For some roof elements the size of the specimen tested in the laboratory will be the same as that installed in the actual building. However, with metal/plastic roofing, membranes and glazed elements, the dimensions used in the real building will often be significantly different from those of the specimen tested in the laboratory. Equation 2 is used to convert the sound intensity level $L_{I(S)}$ in dB re 10^{-12} W/m^2 to a sound power level $L_{W(S)}$ in dB re 10^{-12} W for the in-situ area $S_{(\text{in-situ})}$ in m^2. However, before making any correction from the dimensions of the test specimen in the laboratory to the in-situ dimensions, consideration should be given to the errors that will be introduced by using this simple conversion. Most roof elements comprise plates with critical frequencies above 2 kHz. Below the critical frequency the radiation efficiency of these plates depends upon the plate dimensions. Hence errors can be introduced by using this simple conversion.

$$L_{W(\text{in-situ})} = L_{I(S)} + 10 \log (S_{(\text{in-situ})}) \qquad \ldots(2)$$

Step 3

The final step with Equation 3 is to convert the sound power level $L_{W(S)}$ to the reverberant sound pressure level L_p in dB re 2×10^{-5} Pa in a room of volume V, in m^3, and reverberation time T, in seconds.

$$L_p = L_{W(\text{in-situ})} + 10 \log (4/A) \qquad \ldots(3)$$

where $A = 0.16V/T$.

To calculate the third-octave band sound pressure levels in a single step, the above equations can be combined to give the reverberant sound pressure level, L_p, in dB re 2×10^{-5} Pa as shown in Equation 4.

$$L_p = L_I + 10\log(S.S_{\text{in-situ}}/1\ \text{m}^2) + 10\log(4T/0.16V) \qquad \ldots(4)$$

where S is area of the specimen tested in the laboratory (m^2)

$S_{\text{in-situ}}$ is area of the roof element *in situ* (m^2)

T is reverberation time of the room below the roof element (s), and

V is volume of the room below the roof element (m^3).

Proposed method for demonstrating that rain noise from lightweight roofs and roof elements has been considered when designing schools

At the time of writing, no absolute levels have been established for acceptable sound pressure levels due to rain noise in schools when calculations are made using measured laboratory data with Heavy rainfall. The conversions between different types of rainfall can only be carried out using theoretical models for each type of rainfall for each specific roof element. This becomes particularly difficult for constructions such as ETFE pillows and membrane roofs.

In addition there is the issue of non-constant rainfall rates during real rain storms. Calculation of the indoor sound pressure level from Heavy rain data represents a 'worst-case scenario' for the UK due to the return period of approximately 50 years. Hence an assessment based on Intense rain is potentially more appropriate. To aid design teams until further guidance is developed, a rough rule-of-thumb is proposed based on calculations using real rainfall which indicate that Intense rain could give A-weighted levels that are approximately 20 dB lower than Heavy rain.

The proposal is that the reverberant sound pressure level in a space that has been calculated using laboratory test data with Heavy rain noise excitation as defined in ISO/CD 140-18[3] should not be more than 20 dB above the indoor ambient noise levels in Table 1.1 of BB93[1].

Using laboratory measurement data to calculate the indoor ambient noise level in rooms

Two example calculations are described below.

Example 1

The first example assumes that a classroom has two rooflights each comprising 6–12–6.4 (laminate) glazing of dimensions 1.5 m × 1.25 m. The remaining area of the roof is assumed to be a heavy concrete slab, so only rain noise from the glazing is considered. The area of the roof element *in situ*, $S_{(\text{in-situ})}$, is $3.75\ \text{m}^2$ ($2 \times 1.5 \times 1.25$). The full report[2] gives the area of the 6–12–6.4 glazing that was tested in the laboratory ($S = 1.88\ \text{m}^2$) and the third-octave band sound intensity data from 125 Hz to 5 kHz.

The classroom volume is assumed to be $150\ \text{m}^3$ with third-octave band reverberation times of 0.8 s between 125 Hz and 630 Hz, and 0.6 s between 800 Hz and 5 kHz.

Using Equation 4 for each third-octave band between 125 Hz and 5 kHz, then A-weighting the result gives a reverberant sound pressure level of 51.3 dB $L_{\text{Aeq,30min}}$. From Table 1.1 in BB93[1], the upper limit for the indoor ambient noise level is 35 dB $L_{\text{Aeq,30min}}$; hence this rain noise level would satisfy the rule-of-thumb guidance for a limit of 55 dB $L_{\text{Aeq,30min}}$.

Example 2

The second example assumes that an open-plan resource area has a section of ETFE roof comprising eight ETFE pillows with dimensions 2.23 m × 1.6 m.

The open-plan resource area volume is assumed to be $650\ \text{m}^3$ with third-octave band reverberation times of 0.9 s between 100 Hz and 250 Hz, and 0.65 s between 315 Hz and 5 kHz. Using Equation 4 for each third-octave band between 125 Hz and 5 kHz, then A-weighting the result gives a reverberant sound pressure level of 72.9 dB $L_{\text{Aeq,30min}}$. The application of rain suppressor Type 2 would reduce the level to 59.7 dB $L_{\text{Aeq,30min}}$. From Table 1.1 in BB93[1], the upper limit for the indoor ambient noise level is 40 dB $L_{\text{Aeq,30min}}$; hence the ETFE roof with rain suppressor Type 2 would satisfy the rule-of-thumb guidance for a limit of 60 dB $L_{\text{Aeq,30min}}$.

References

[1] **Department for Education and Skills.** *Acoustic design of schools.* DfES Building Bulletin 93. London, The Stationery Office, 2004.

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[3] **International Standards Organization.** Acoustics – Measurement of sound insulation in buildings and of building elements – Part 18: Laboratory measurement of sound generated by rainfall on building elements. *International Standard* ISO/CD 140-18 (ISO TC43/SC2 N 0751 13 January 2004).

[4] **British Standards Institution.** Acoustics – Measurement of sound insulation in buildings and of building elements using sound intensity. Part 1: Laboratory measurements. *British Standard* BS EN ISO 15186-1:2003.

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Garston, Watford WD25 9XX
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IP 2/06

January 2006
ISBN 1 86081 898 6