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Rain noise

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ABSTRACT

In this paper we discuss the requirements of the generic international standard (ISO, BS EN ISO 10140) for testing of sound transmission through sample roofs exposed to simulated rainfall and of lessons learned during a recent test program. The test data forms the basis for calculating in-situ sound levels in rooms beneath the roof and we discuss the differences in sound produced by simulated rain to that of natural rain. The differences in impact velocity and raindrop distribution between simulated and natural rain are key factors that are not addressed by the Standard. In addition, an optional normalization test using a pane of glass is included, for the explicit comparison of products tested and as quality control for test laboratories, and its results have been incorrectly shown in some manufacturer's publicity material as the basis for calculating room sound levels. The Standard does not specify whether the normalization test should be carried out as a skylight or as glazing but the two tests have different requirements. Being optional and intended for inter-lab comparison suggests that the normalization data should not be released to clients as it is misleading and thus should be excluded from reporting.

Keywords: rain noise, roof systems

1. INTRODUCTION

Depending upon the listener's contextual situation, noise generated by rainfall can be soothing or annoying. Lengthy *You Tube* videos and *mp3* audio are available (1) for playing rain noise to support relaxation, yet in other circumstances the same sound masks communications and becomes a nuisance. It is in this latter context that we report on the incidence of rainfall on metal roofs supported by structural insulated panels (SIPs) forming the roof of an interior space in a building. These panels are composite structures typically consisting of a soft elastic core bonded to stiff facing panels such as oriented strand board, magnesium oxide board and plywood. The intrinsic mass is low and the consequent poor acoustic insulation properties may lead to high levels of rain induced noise in the building's interior rooms. The rooms in question could be classrooms or open learning spaces where good conditions for communication for teaching are paramount (2).

Figure 1 shows the typical form of response curve for the sound transmission loss characteristic of foam cored SIPs. The dips at frequencies around 630 Hz and 3150 Hz control the STC rating for the panel. The response in the range of 630 Hz is a bounce mode of the masses of the facing panels on the springy foam core. Adding mass layers (as in the red curve in Figure 1) to improve the transmission loss rating also stiffens the panel but the upper and lower modal frequencies are relatively unchanged. The second mode frequency is reduced as there is an inverse linear relationship between frequency and added mass as the core spring stiffness is unchanged. The effect on the NC rating due to rain noise, as determined for a room where SIPs are used in a roofing application, can be seen in Figure 2, plotted for rain noise. Clearly, the resonance mode in the 630 Hz region is limiting the rating for the room.

Rain noise is the result of vibration of the surface on which the rain falls and as it propagates through the surface and structure its character is changed by the structure's mass, material damping and resulting energy loss. Currently SIPs offer little in terms of acoustic attenuation and must be treated by adding surface mass layers such as plasterboard, medium density fibreboard (mdf) or

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plywood and/or damping materials (membranes, paints). Alternative methods of damping and surface treatment reported by Wawrzynowicz et. al. (3) showed mixed results.

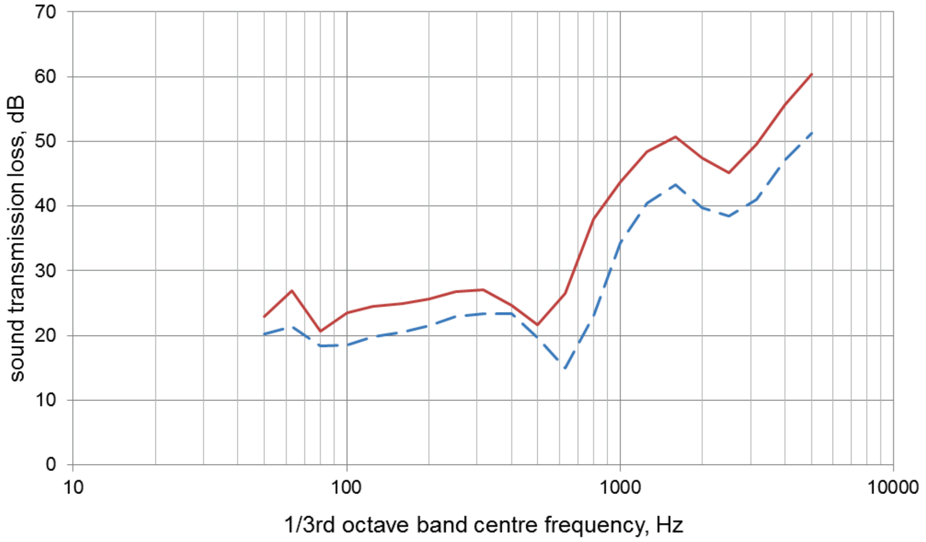

Figure 1 - Typical sound transmission loss curves for SIPs – blue broken line is bare SIP, red line is SIP with one layer direct fixed plasterboard.

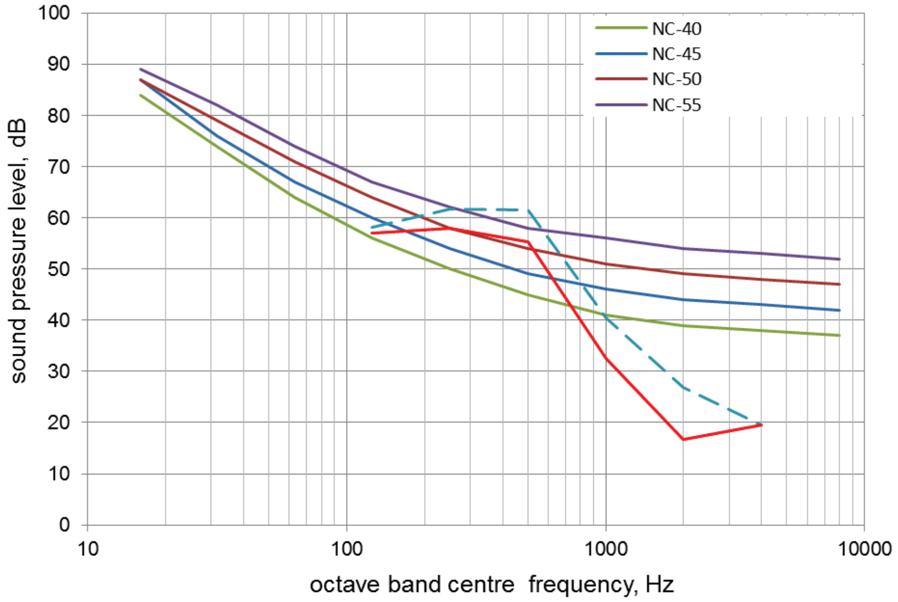

Figure 2 - Sound level in a room with a SIP roof exposed to rain noise. The broken line represents a SIP with additional face treatments and the red line shows the effect of adding insulation (with a suspended ceiling).

2. RAIN

Rain is a form of impact loading, generating noise by the excitation of vibration of roof panels by the dynamic force exerted by the falling droplets. The size of raindrops varies in natural rain and is related to the intensity or rainfall rate. Rain is classified as light, moderate, heavy or intense. In the laboratory, simulated rain as defined in Standards (4) is classified as moderate, intense, heavy or cloudburst, and is generated in the laboratory as a means to make observations under reproducible and standard conditions. It does not correlate well with natural rain but the spectral character of the noise is consistent, whilst the sound level is at variance. The impacting raindrops excite the natural modes of vibration of the exposed roof panel and the resulting motion is radiated as sound. Lower frequency modes require higher input energy to excite and so may not be present in low intensity rain. The modal frequencies of the roof structure are determined by the mass, boundary conditions (screw or nail fixing and their spacing), the spacing and material of the purlins, and system damping (overlap joints, membranes, material). For a given installation an increase in rainfall rate consequently leads to higher noise being generated. The construction and installation of the sample for testing must be as close as possible to the actual site installation to provide any confidence in the accuracy of predictions of sound levels from the test results. The curtain wall that supports the sample should have a similar construction to the exterior walls of the building design and the junction between the test sample and the wall should be as similar as possible. This becomes a test on the structure rather than simply the roof section. Altering boundary conditions where the roof sample joins the supporting curtain wall alters the response characteristics of the roof sample and so the sound produced will be different than under actual site conditions making predictions difficult and erroneous.

Simulated rain is different from natural rain as it seeks to standardize a testing method. Simulated rain must comprise 50% of the volume flow of droplets of the same size and have a specified impact velocity where in natural rain the drop size distribution is related to rainfall rate and therefore each event will have a different impact velocity distribution (6).

Rain noise testing is carried out to the international standard BS EN 10140-Part 1, Appendix-K (4). Parts 3 and 5 of the older standard ISO 10140 are referenced in the test methodology (5,7), and details of the drip tray for generating water droplets is detailed in amendment 1 to part 5 (8). This includes a table where the hole size and number of holes per unit area is given, but surprisingly there is no specification of the hole entry and exit conditions. The holes are 1 mm diameter so small enough for surface tension and edge effects to play a significant role in capillary flow and drop formation (9).

The laboratory test for a roof system uses a drip tray whose area is only a fraction of the test sample area and three test positions are required – not overlapping and offset from the centre to avoid symmetry. The size of the drip tray given in the Standard is 1.25 m x 1.3 m (1.625m^2) that has approximately 60 holes/m^2 – and the standard states “a random distribution is preferred.” The figure in the Standard shows division of the tray into 100 rectangles each with a single hole – the pattern appears to show each hole in one of four positions within the rectangle and so not truly random. We determined that no hole should be closer than 10 mm from a wall of the tray so that the area over the holes is 1.56 m^2 and the number of holes/m^2 is 64. One possible sample hole pattern is shown in Figure 3:

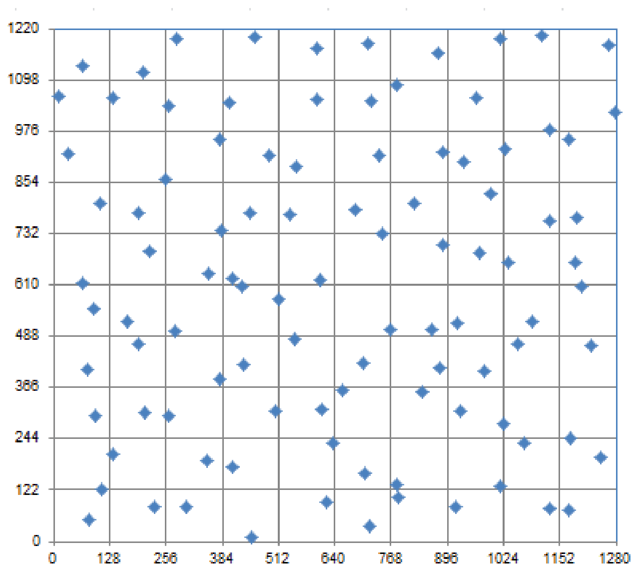

Figure 3 – Sample of random hole positions for the drip tray.

The required rainfall rate is 40 mm/h, that is, collected over a period of one hour, the depth of water over the area of the trip tray will be 40 mm. Thus the volume flow required is (1.56 x 0.04) or 0.0624 m^3/h. The flow through each hole is 1/100 of this, i.e. 6.24E-4 m^3/hole. The volume flow is:

$$q = KA(2gh)^{0.5} \qquad \text{Equation 1}$$

where $K = C_e C_d C_v$ is the product of the flow coefficients for entry, discharge and velocity conditions respectively, A is the cross-sectional area of a hole, m^2, and h is the depth of water in the drip tray, m. Thus,

$$h = (q/KA)^2/2g \qquad \text{Equation 2}$$

and inserting values gives $h = 0.0038$ m or 3.8 mm. A value of K = 0.8 has been assumed here but this could easily be as low as 0.5 if the edges of the holes are sharp (9). It should be noted that the depth of water required is very shallow compared to the dimensions of the tray and levelling must be precise in order to obtain uniform drip formation across its area. Increasing the depth of water in the tray will increase the flowrate and lower the drip size, or lead to stream flow if too deep.

Water droplets form at the exits from the holes and detach when their internal pressures generated from their mass and gravitational force exceeds the capacity of surface tension to keep them intact. Assuming a spherical droplet, the force due to surface tension is given by the expression:

$$F_t = 2\pi r\gamma \qquad \text{Equation 3}$$

where γ is the surface tension, r is the radius of the water droplet, m. This force is balanced by the gravitational force mg, N, due to the mass of water in the droplet and so:

$$r = mg/2\pi\gamma \qquad \text{Equation 4}$$

Inserting values gives d = 0.0047 m or 4.7 mm. Thus, assuming the correct head of water, drips will naturally form at the exit of the holes that are approximately the correct size.

3. SOUND GENERATION

Sound is generated by the impacting droplets exciting vibration of the roof surface. Some sound is radiated into the environment and some passes through the structure into the space below. The latter is the portion we are mainly interested in, but in-situ flanking issues may also require examination of the former. Predicting the level of sound propagating through roofs has been researched for many years and remains a task to be solved as the level of confidence in results from the process is questionable (10). Approximate solutions have been suggested but no reliable method has evolved. There are several reasons for this but the main ones are the inability to model a flexible orthotropic composite panel system in a simple manner, defining the characteristics of the impact force on a flexibly mounted surface, and the effects of pooled or run-off water that is on the roof surface. The response of the roof system is dependent upon the materials used, the method of construction and the boundary conditions - and these are far from simple. In addition there is the difference between natural rain and simulated rain and yet there appears to be an expectation that a laboratory test will give the expected noise characteristics for the roof system directly.

Testing is still the best way to achieve any certainty in forecasting the sound levels in rooms below a specified roof but it is expected that different laboratories will get different results for the same product. This is because the results are dependent upon the degree of care in preparing and installing the sample and the degree to which the boundary conditions will match those resulting from site construction – in addition to the variable nature of the drip tray. Following testing, the laboratory provides the value of the averaged sound intensity measured for rainfall over three test positions. This is a small percentage of the total area of the sample and so the reported intensity must be scaled up as if rain fell on the whole sample. The data must be further modified to suit the dimensions and acoustic character of the room where a prediction is sought, and then further modified to allow for natural rain in lieu of simulated rain – since simulated rain has a lower terminal velocity and different spatial and temporal characteristics.

The standards include an optional reference test using a glass pane for quality control and in order to compare results from different laboratories. The way in which this pane is actually mounted and tested however is not specified and yet a table of reference values for sound intensity is given and the test results are compared to this and 'correction' factors derived. These factors are then applied to rain noise test results for sample roofs tested in the same lab. The mounting conditions are different, the exposed area is different and the angle of the surfaces may be different, so we are unsure of what the rationale behind applying the 'corrections' is. In two instances we know of, this exercise returned lower values of intensity (L_{Inorm}) than the measured values (L_I) and the clients have published the lower values as a basis for room calculations. In one case the laboratory report only showed the L_{Inorm} result. Clearly, since the glass pane test is optional it cannot be the basis for room calculations - nor for intercomparisons of product tests between laboratories as the mounting conditions are not fully specified. Appendix I of [5] explicitly states that the glass pane is for reference use.

The education sector in many countries now specify sound levels to be achieved in learning spaces and so if remedial costs are to be avoided (after site testing) then predictions of sound levels and testing need to be more reliable and reproducible.

4. EXAMPLE SIP

A sample roof construction from 265 mm thick SIP was tested under simulated rainfall of 40 mm/h. A 0.55 mm metal tray roof mounted on cavity battens on a waterproof membrane was laid over the SIP and a suspended ceiling installed below, carrying 50mm thick mineral fibre tiles. Standard details were used for all construction. For predictions a learning space of 200 m^2 was used with a volume of 800m^3 and reverberation times of 0.6 s (100 to 500 Hz) and 0.4 s (600 to 5000Hz). The results are shown in Table 2.

Table 2 - Application of test results for metal tray roof over a structural insulated panel roof

1/3rd Octave band frequency, Hz	From the test sample			
	$L_{i,\ dB}$	$L_{i(s),\ dB}$	$L_{w,\ dB}$	$L_{p(in\text{-}situ)}$
100	40.50	50.6	73.6	57.2
125	40.90	51.0	74.0	57.7
160	41.70	51.8	74.8	58.5
200	44.40	54.5	77.5	61.2
250	44.70	54.8	77.8	61.5
315	44.70	54.8	77.8	61.5
400	46.10	56.2	79.2	62.9
500	45.40	55.5	78.5	62.2
630	40.00	50.1	73.1	56.8
800	27.40	37.5	60.5	44.2
1000	18.60	28.7	51.7	35.4
1250	14.00	24.1	47.1	30.8
1600	12.20	22.3	45.3	29.0
2000	9.80	19.9	42.9	26.6
2500	4.90	15.0	38.0	21.7
3150	1.50	11.6	34.6	18.3
4000	2.10	12.2	35.2	18.9
5000	3.80	13.9	36.9	20.6

L_I is from test SPL or measured directly.
$L_{I(s)} = L_I+10*log(S_s/S_o)$, where
S_s is the roof sample area, m^2
S_o is the reference area for rainfall = (1 m^2).
L_W is the sound power radiated by the roof system into the room (area S_R) and is given by:
$L_W=L_{I(s)}+10log(S_R)$
and then
$L_{p(in\text{-}situ)}=L_W+10log(4T_{60}/0.16V)+1.7$
*where V is the room volume (m^3), and T_{60} is the reverberation time (s). The addition of 1.7 dB is for natural rain (4)**

NOTE: * The 'correction' for natural rain consists of -3.6dB for the difference in drop size distribution compared with simulated rain and +5.3dB for the terminal velocity impact of natural rain (6) – but note that this is based on rain in Beijing and may be different in another location.

The in-situ calculated data is plotted in Figure 4 against in-situ data calculated simply from the reported intensity from a laboratory test without scaling for the difference between sample size and area of sample actually exposed to rain. The latter is further not modified by the correction for natural as opposed to artificial rain.

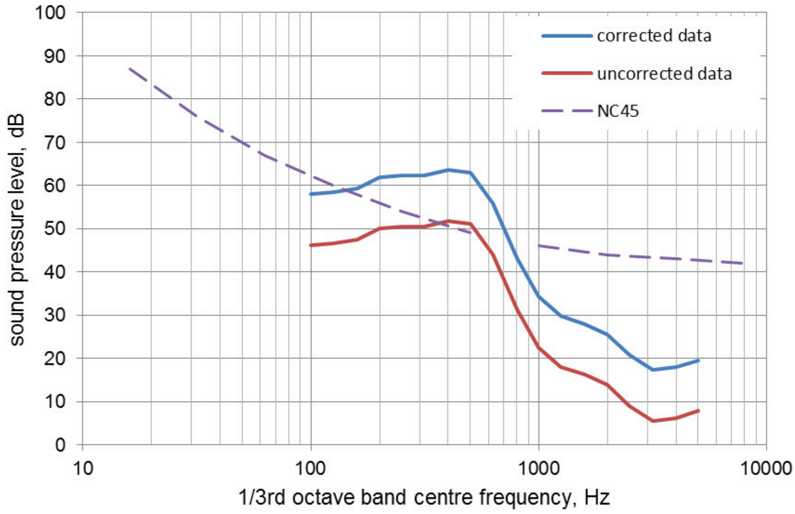

Figure 4 – Variance from NC45 curve for rain noise on a SIP showing: a) test data corrected for sample size and natural as opposed to artificial rain, and b) uncorrected data – based simply on intensity from the test report.

Figure 4 shows a significant difference in reported data with one result almost compliant with the specified NC level for the room and the other results some10 to 12 dB above it. It is incumbent upon the acoustician to ensure clarity in use of laboratory data and on manufacturers to publish the right data – not necessarily the lowest. Hopkins (11) sets out a methodology – but cautions on using the simple assumption of linearity in response of the roof system and errors that are inevitable in scaling from a test sample to a full size in-situ roof system.

5. CONCLUSIONS

The suite of standards for testing roof system exposure to simulated rain is not sufficiently clear or precise enough to avoid differences between laboratories nor between tests on different products in the same laboratory. More control is required on the entry and exit conditions for the drip tray holes to ensure consistent performance. Less noise is produced by a stream of water onto a roof surface carrying a film of water than is the case for dripping. Simply measuring the flowrate as a form of calibration/validation is not sufficient.

Laboratory reports need to make it clear that the reported intensity is for the sample being rain impacted over only a small portion of the total (unless a skylight test), and report on the total sample size since it is required in order to correct SPL for excitation over the whole sample. Furthermore there seems to be no value in modifying the test data by correction factors derived from a sample glass pane test and issuing that data to clients. The standard does not delineate in sufficient detail how the reference pane is to be mounted and tested in order to achieve uniformity between labs – and, furthermore, is optional.

Prediction of rain noise levels remains a *black art* but it is hoped that more testing will be prompted by new guidelines and specifications, such as those in the education and health sectors, the results of which will encourage development of more accurate models and lead to more reliable predictions.

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REFERENCES

1. https://www.youtube.com/watch?v=IdGUunu7pVI for example (accessed 20th Sept 2018).
2. Minstry of Education, Designing Quality Learning Spaces: Acoustics. Vers2.0, Sept 2016, Min. of Education, New Zealand.
3. Wawrzynowicz, A.; Krzaczek, M.; Tejchman, J., 2014. Experiments and FE Analyses on airborne sound properties of composite structural insulated panels. Arch. of Acoustics, vol 39(3), 351-364.
4. BS EN ISO 10140-1:2016 Acoustics - Laboratory measurement of sound insulation of building elements. Part 1: Application rules for specific products, Appendix K Roofs, roof/ceiling systems, roof windows and skylights - rainfall sound.
5. ISO 10140-5 2010, Amm-1 2014. Acoustics – laboratory measurement of sound insulation of building elements Part 5: requirements for test facilities and equipment Amendment 1: Rainfall sound.
6. Yan Xiang; Lu Shuai; Li Junjie 2016 Experimental studies on the rain noise of lightweight roofs: natural rains vs artificial rains. Applied Acoustics 106(2016) 63-76.
7. ISO 10140-3:2010 Acoustics – laboratory measurement of sound insulation of building elements Part 3: Measurement of sound impact insulation.
8. ISO 10140-5 2010, Amm-1 2014. Acoustics – laboratory measurement of sound insulation of building elements Part 5: requirements for test facilities and equipment Amendment 1: Rainfall sound.
9. Ghassemieh, E.; Versteeg, H.K.; Acar, M. 2006. The effect of nozzle geometry on the flow characteristics of small water jets. Proc. IMechE Vol 220 Part C: J. Mechancial Engineering Science, 1739-1754.
10. Griffin, D. Accuracy of prediction methods for predicting rain noise. Internoise 2016, Hamburg, Germany.
11. Hopkins, C. Rain noise from glazed and lightweight roofing. UK Building Research Establishment IP2/06.