inter.noise 2000
The 29th International Congress and Exhibition on Noise Control Engineering
27-30 August 2000, Nice, FRANCE

I-INCE Classification: 4.3

LABORATORY TEST SET-UP FOR THE EVALUATION OF RAINFALL-NOISE

G. Vermeir*, P. Mees**

* Laboratory of Acoustics, Laboratory of Building Physics, Catholic University of Leuven, Belgium, Celestijnenlaan, 131, B 3001, Leuven, Belgium

** Daidalos Bouwfysisch Ingenieursbureau, Leuven, Belgium, Rodenbachstraat, 71, B 3010, Leuven, Belgium

Tel.: +32 16 321349 / Fax: +32 16 321980 / Email: gerrit.vermeir@bwk.kuleuven.ac.be

Keywords:
BUILDING ACOUSTICS, RAINFALL NOISE, STRUCTURAL NOISE, MEASURING TECHNIQUES

ABSTRACT
This paper presents an analysis of a laboratory set-up for the combined evaluation of rainfall noise and airborne sound insulation. The purpose of the set-up is to obtain repeatable measurement data on impact and airborne sound insulation of roof constructions. For the impact sound insulation, two measurement methods are presented. The first method uses artificial rainfall created by a series of nozzles suspended above the roof sample; this is the 'wet' method. The second method uses mechanical excitation by means of an impact hammer; this is the 'dry' method. In both methods, the sound intensity radiated towards the receiving room is measured. The paper discusses both methods in detail by means of measurements results obtained on lightweight aluminum roofs. A comparison is made with earlier results obtained on single and double glass.

1 - INTRODUCTION
Modern architecture makes extensive use of lightweight constructions, e.g. metal roofs, horizontal or inclined glazing, ... It is known from experience that rainfall may generate excessive noise in interior spaces or may even interfere with normal activities by disturbing the speech intelligibility.
The mechanical excitation by rainfall depends on numerous parameters: rainfall rate, drop size, raindrop velocity, boundary water layer, ... These elements are discussed in [1-4]. Experimental results reported relate to natural rainfall on a single steel plate roof [1], artificial rainfall on different roof structures [1-4], artificial rainfall on single and double glass [5]. Vermeir, Mees also use a theoretical simulation to predict the effects of adding damping layers to glazing [5].
The preparation of an ISO standard that specifies (a) measurement method(s) for the sound radiated by rainfall on roofs is ongoing (ISO/TC 43/SC 2/ WG 18). A major difficulty is to agree on an excitation method. The ideal method should be representative for real rainfall, should give repeatable results and should be practical to implement in a laboratory.
The principal aim of this paper is to compare two measurement methods for determining the noise radiated by rainfall. In the first method, a roof sample is excited by artificial rainfall in the laboratory. This 'wet' method is an attempt to approach real rainfall in the best possible way, but is rather difficult to implement as a routine test a laboratory. In the second method, the roof is excited by means of an impact hammer. This 'dry' method is different from excitation by real rainfall but is easier to implement as a routine test in a laboratory.
Both methods have been applied to single and double glass [5] and to lightweight aluminum roofs. These tests can be considered as extreme cases. Single and double glass are examples of simple, homogeneous structures with well-known material characteristics and simple boundary conditions. The lightweight aluminum roofs are examples of complex, inhomogeneous structures with different material layers, line and point connections, and complex boundary conditions. This paper presents results for three compositions of the same roof-type: a standard composition, a roof with increased mechanical damping and a roof with increased decoupling of the different layers.

The first part of the paper presents the experimental set-up and the composition of the roofs. The second part presents the measurement procedures. The final part of the report discusses the measurement procedures and the results obtained.

2 - TEST SET-UP AND SAMPLES

Figure 1 shows a longitudinal cross-section of the experimental set-up. The roof sample is mounted in the horizontal measurement opening between two transmission rooms of the Laboratory for Acoustics and Thermal Physics. The construction of the laboratory satisfies the requirements of ISO 140-1 [6]. The supporting structure is a double wall around the measurement opening, with a horizontal inclination of 5 degrees towards one side of the laboratory.

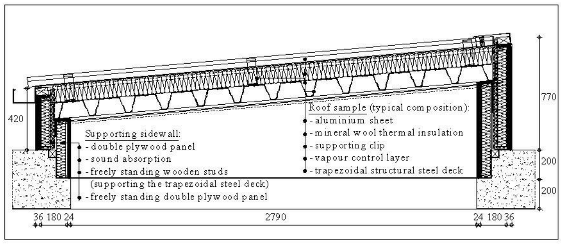

Figure 1: Longitudinal cross section of the test set-up.

Artificial rainfall is generated by sixteen upwardly directed nozzles suspended at an average height of 2.7 m above the test sample. In each nozzle, 6 holes of 1.2 mm diameter are drilled with an offset and a small inclination from the axis of the nozzle. In this way, the sixteen nozzles act as small fountains, and raindrops are falling freely from a average height of approximately 3.0 m on the test sample. The rainfall rate is controlled by means of a pressure regulator in a closed water circuit. Figure 2 shows a close-up photograph of a nozzle.

Figure 2: Photograph of nozzle.

For discussing the measurement procedures, we consider three lightweight aluminum roofs tested in the set-up. Common elements of all roof types are (from bottom to top): a trapezoidal structural steel deck, a vapor control barrier, a mineral wool thermal insulation and an aluminum roof sheet on aluminum clips. The three types are different in the following respect:

- Type 1: as described above;
- Type 2: as Type 1, with the aluminum roof sheet damped by a bituminous layer;
- Type 3: as Type 1, with clips mounted on intermediate studs between the clip foot and the structural steel deck.

3 - MEASUREMENT PROCEDURE

For each roof sample, three quantities are measured: the airborne sound insulation, the sound intensity radiated by mechanical excitation with artificial rainfall, and the sound intensity radiated by mechanical excitation with an impact hammer.

The airborne sound insulation is measured according to ISO 140−3 [7].
For the artificial rain special care has been taken to keep the rainfall rate constant during the whole measurement campaign. Therefore, the rainfall noise radiated by different roof samples can directly be compared. In each test, the rainfall is switched on during 15 minutes, and the sound pressure level in the receiving room is constantly monitored to verify the assumption of constant rainfall. The average sound pressure level in the lower room is measured by means of a rotating microphone. From this result, the sound intensity level radiated by the roof is calculated as follows:

$$L_I = L_{pr} + 10\log\left(\frac{A}{4S}\right)$$

where:

- L_I: the radiated sound intensity level [dB ref 1x10^{-12} W/m^2];
- L_{pr}: the average sound pressure level, measured in the receiving room [dB ref 2x10^{-5} Pa];
- A: the sound absorption area in the receiving room [m^2];
- S: the (radiating) surface of the roof (in the current setup, $S = 7.81$ m^2).

This quantity is independent of the surface of the roof and of the sound absorption in the receiving room. It is mainly dependent on the excitation (in particular on the rainfall rate) and on the composition of the test sample. A single, A-weighted sound intensity level $L_{I,A}$ is calculated from the sound intensity levels in the one-third octave bands from 50 Hz to 5000 Hz.
As an alternative to the measurement of rainfall noise by means of artificial rain, the sound radiation by mechanical excitation with an impact hammer is measured for each test sample. Both sources can be considered as mechanical forces acting on the top surface of the sample. It is therefore anticipated that similar conclusions can be drawn from both experiments with regard to the sound radiation of roofs exposed to real rainfall.
In this experiment, the top surface of the roof, the aluminum sheet facing the source room, is continuously hit by means of an impact hammer, at a rate of approximately 3−4 impacts/second. During the small interval between two impacts, the operator changes the point of impact along a random trajectory on the surface. This procedure takes 30 seconds, during which the force at the impact point and the sound pressure level in the receiving room are simultaneously averaged. The impact force is measured by means of a force transducer attached to the hammer tip. The sound pressure level is measured by means of a microphone in the receiving room. The measurement procedure is repeated 9 times, to cover the 9 different roof sheets.
From the averaged force level and the averaged sound pressure level in the lower room, the normalized sound intensity level radiated by the roof is calculated as follows:

$$L_I = L_{pr} + 10\log\left(\frac{A}{4S}\right) - L_F$$

where:

- L_I: the radiated sound intensity level [dB ref 1x10-12 W/m^2];
- L_{pr}: the average sound pressure level, measured in the receiving room [dB ref 2x10^{-5} Pa];
- A: the sound absorption area in the receiving room [m^2];
- S: the (radiating) surface of the roof (in the current setup, $S = 7.81$ m^2);
- L_F: the average force level, measured by the impact hammer [dB ref 1 N rms].

The quantity L_I essentially represents the sound intensity level radiated by the sample, excited by a randomly positioned point force with unit amplitude. The 9 individual measurement results, obtained on the partial surfaces of the test sample, are processed independently according to the given formula. The 9 results are averaged to obtain the final value of the normalized radiated sound intensity level L_I. For each test sample, the whole experiment is performed twice, using an impact hammer with a hard plastic tip and with a steel tip, respectively.

4 - DISCUSSION OF RESULTS

In this section the 'wet' and 'dry' methods are discussed by means of the results obtained on the lightweight aluminum roofs and on glass roofs [5]. First, the accuracy of the individual methods is checked. Second, it is investigated whether the 'dry' method can substitute the 'wet' method in a systematic way.

The accuracy of the measurement with artificial rainfall depends on the ability to reproduce identical rainfall rates and patterns over long periods of time. It has been found earlier [5] that by careful operation, the standard deviation of the 'wet' method is 3 dB at individual frequency bands and 1 dB(A) for the A-weighted sound radiation.

Within the linear response of the test sample, measurement results obtained with the impact hammer are independent of the force applied. However, as the hammer is manually operated, following an irregular pattern, measurements on individual parts of a structure can be different. But the standard deviation (1 dB is a typical value for each third octave band result) and the maximum deviation of the radiated sound intensity between series of impacts (30" each) on the same sample show only very small deviations. The results for the complex roof show larger deviations (stdv typically 2 dB), with a tendency for the largest deviations on the roof with the highest damping. The heterogeneous roof is more susceptible to 'accidentally' different impacts, and due to the numerous point connections between layers, the transmission through the roof structure depends on the exact impact point.

The 'dry' method can be a substitute for the 'wet' method if identical conclusions can be drawn from both tests on different samples.

As a first check, it was investigated whether variations within the same type of samples are detected in an identical way by both methods. Figures 3 and 4 show the reduction of the radiated sound intensity by adding damping to a sample. Figure 3 is the result for a single glass plate being replaced by a layered glass plate. Figure 4 is the result for roof type 1, without damping, being replaced by roof type 2, with a damping layer on the aluminum sheet. The results show that the supplementary reduction is equally well predicted by both measurement methods. For the roof, however, the correspondence between the 'wet' and 'dry' method is not so good as for the glass. An identical conclusion holds when the effect of structural decoupling within a sample on the radiated intensity is investigated. Figure 5 is the result for a single glass plate being replaced by a double glass with intermediate air layer. At low frequencies, the double glass radiates more sound, and a positive reduction only starts above the mass-spring-mass resonance frequency. Figure 6 is the result for roof type 1 being replaced by roof type 3, with structural decoupling between the top sheet and the structural steel deck. A significant reduction of the radiated sound intensity is noted at middle and high frequencies.

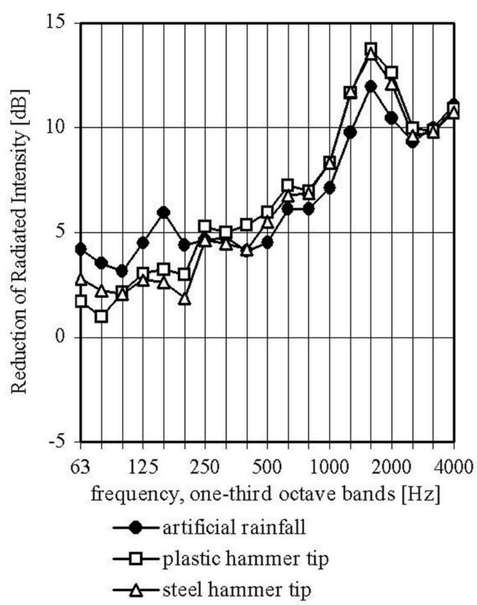

Figure 3: Measured improvements due to the additional layering of the single glass pane.

As a second check, it was investigated whether the difference between the 'wet' and the 'dry' method is identical over all samples tested. Both methods have now been applied to radically different structures. Ideally, the difference between the radiated sound intensity levels obtained by both methods should

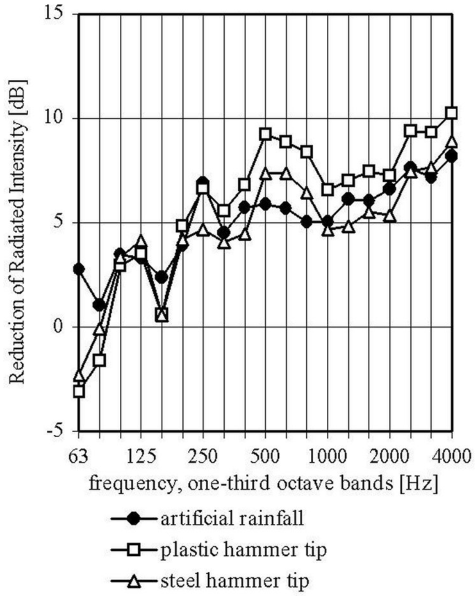

Figure 4: Effect of additional damping layer (type 1/type 3).

be independent of the test sample under investigation. This would not only allow to compare the performance of different test samples, but also to establish a fixed relation between the sound intensity level measured with an impact hammer and the sound intensity level of real rainfall noise. Unfortunately, this does not seem to be the case. Figures 7 and 8 show the difference between the sound radiation measured by the 'wet' and the 'dry' methods, for all glazing panes and for all lightweight roof structures tested. Within one category of structures, the difference is constant and a fixed relation between the results of both measurement methods can be established. Between different categories of structures, it seems impossible to establish a fixed relation between the 'wet' and the 'dry' test method.

5 - CONCLUSIONS

As laboratory set-up has been presented that allows the simultaneous measurement of the airborne sound insulation and the sound radiation by rainfall. Rainfall noise is measured by artificial rain, the 'wet' method, and by excitation with an impact hammer, the 'dry' method. For lightweight roof structures, it was shown that both damping and structural decoupling are efficient ways to reduce rainfall noise. About the measurement method, it was concluded that the 'dry' method is a good substitute for the 'wet' method in parametric studies within a given category of structures. However, the 'dry' method does not seem to be a good tool for making reliable comparisons between totally different structures.

REFERENCES

1. **P. Dubout**, The sound of rain on a steel roof, *J. Sound Vib.*, Vol. 10(1), pp. 144-150, 1969

2. **K.O. Ballagh**, Noise of simulated rainfall on roofs, *Applied Acoustics*, Vol. 31, pp. 245-264, 1990

3. **J.McLoughlin, D.J. Saunders, R.D. Ford**, Noise generated by simulated rainfall on profiled steel roof structures, *Applied Acoustics*, Vol. 42, pp. 239-255, 1994

4. **H. Suga, H. Tachibana**, Sound radiation characteristics of lightweight roof constructions excited by rain, *Journal of Building Acoustics*, Vol. 1(4), pp. 249-270, 1994

5. **G. Vermeir, P. Mees, I. Bosmans**, Prediction of rainfall noise on single and double glazing, In *Inter.Noise 96*, pp. 523-528, 1996

6. **ISO**, *140-1 Acoustics - Measurement of sound insulation in buildings and of building elements - Part 1: requirements for laboratories*

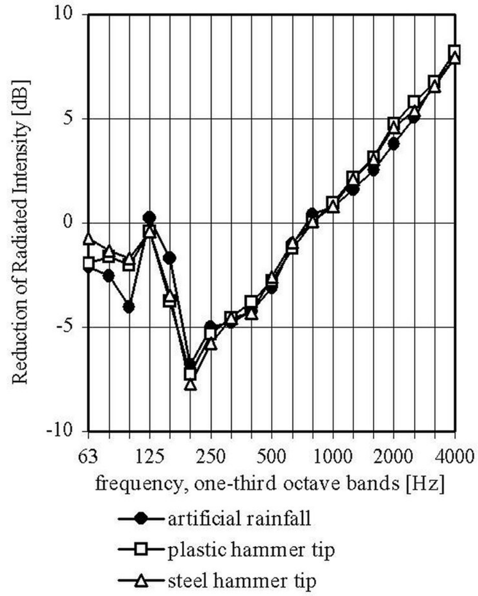

Figure 5: Improvements due to the use of double glazing compared to single glazing.

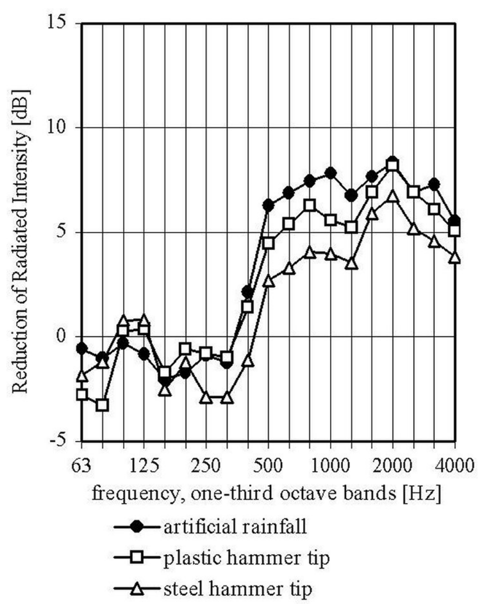

Figure 6: Improvements due to a structural decoupling in the metallic roof construction (type 3).

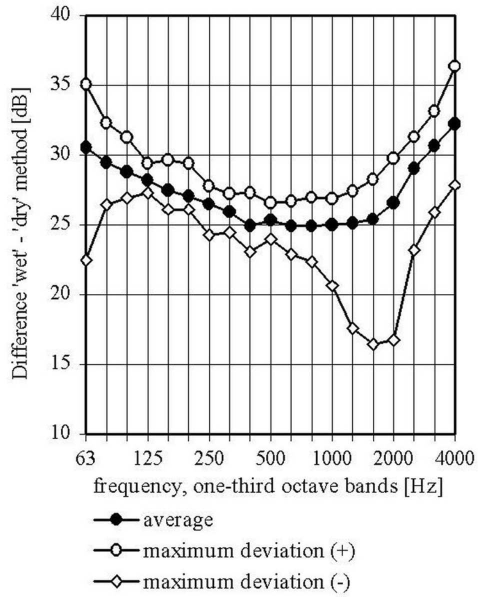

Figure 7: Differences 'wet tests' compared to 'dry tests' for all tested glazings.

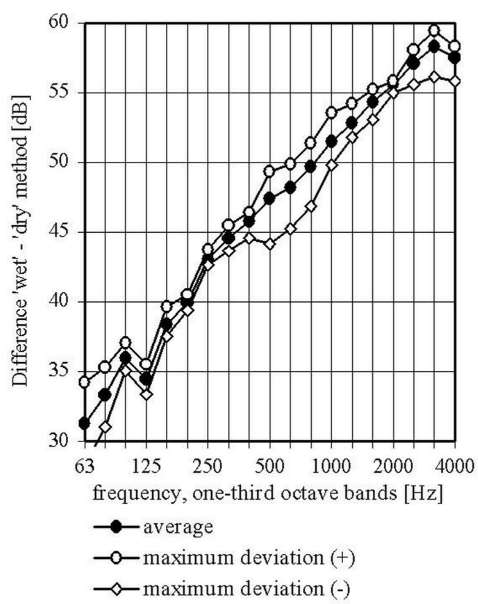

Figure 8: Differences 'wet tests' compared to 'dry tests' for all tested metallic roofs.